DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

STUDIES RELATED TO WILDERNESS

The Wilderness Act (Public Law 88-577, September 3, 1964) and related acts require the U.S. Geological Survey and the U.S. Bureau of Mines to survey certain areas on Federal lands to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report discusses the results of a geochemical survey of the Sangre de Cristo Wilderness Study Area, Rio Grande and San Isabel National Forests, Fremont, Saguache, Custer, Huerfano, Alamosa, and Costilla Counties, south-central Colorado. The area was designated as a wilderness study area under Public Law 96-560 in 1980.

ABSTRACT

A trace-element geochemical study of the Sangre de Cristo Wilderness Study Area included the collection of 710 heavy-mineral-concentrate samples, 767 minus-80 mesh stream-sediment samples, and 145 rock samples. All samples were analyzed for 31 elements by semiquantitative emission-spectrographic methods, and some stream-sediment and rock samples were also analyzed for selected elements by wet chemical methods.

Trace-element geochemical anomalies, including Cu, Pb, Zn, Cd, and As in stream-sediment samples or Cu, Pb, Ba, Mo, W, Sn, Au, Bi, and Zn in heavy-mineral-concentrate samples, outline areas of: (a) quartz-veining and (or) metallization associated with fractured rock throughout much of the study area, including much of the Sangre de Cristo fault system, parts of the Alvarado fault system, and areas in the vicinity of Blanca Peak; (b) porphyry-type mineralization in the vicinity of Cottonwood Peak; (c) redbed-type uranium-copper mineralization associated with upper Paleozoic clastic sedimentary rocks; and (d) possible stratabound metal deposits in Precambrian gneiss in the northern part of the study area.

INTRODUCTION

This package of geochemical maps and interpretations comprises the geochemical contribution to the mineral resource evaluation of the Sangre de Cristo Wilderness Study Area, south-central Colorado (fig. 1). Other parts of the evaluation include a mineral resource potential report by Johnson and others (1984a), a geologic map by Johnson and others (1984b), and a study of known prospects and mines by Ellis and others (1983).

The geochemical investigation consisted of a pilot study, used to determine the most effective sample media for the definition of the known mineral deposit types in the study area, followed by a regional-scale stream drainage sampling program and a rock sampling program at selected mines and prospects. The total number of samples which were collected include 710 heavy-mineral-concentrate samples, 767 minus-80 mesh stream-sediment samples, and 145 rock samples. All samples were analyzed for 31 elements by semiquantitative emission-spectrographic methods, and some rock and stream-sediment samples were also analyzed for selected elements by wet chemical methods.

GEOLOGY

The two most common rock types in the study area are Precambrian crystalline and upper Paleozoic clastic sedimentary rocks. Other rock types which occur in less voluminous amounts include lower Paleozoic sedimentary rocks, including carbonates; Jurassic sedimentary rocks; and Tertiary plutonic, volcanic, and sedimentary rocks. Two structural styles are common in the study area. These include a period of compressional tectonics during Laramide time, which produced a series of thrust sheets, and a younger (Oligocene to Recent) period of extensional tectonics, which produced the presently exposed horst-and-graben configuration of the Sangre de Cristo Mountains and the San Luis and Wet Mountain valleys.

Recent mapping by members of the U.S. Geological Survey resulted in a regional-scale (1:62,500) map (Johnson and others, 1984b) from which much of the geologic information presented below was taken. Other geologic studies from within the study area include structural and stratigraphic studies of the northern part of the Sangre de Cristo range by Gableman (1952) and Litsey (1958) and a petrographic and petrologic study of the Rito Alto stock by Toulmin (1953).

PRECAMBRIAN ROCKS

Precambrian metamorphic rocks are divided into two groups on the geologic map, corresponding to rocks whose original volcanic texture is still identifiable (Xvs) and gneisses whose original texture is not identifiable (Xgn). The metavolcanic rocks are confined to the northern part of the study area whereas the gneisses occur in the northern, west-central, and southern parts of the study area.

There are three apparent ages of Precambrian intrusive rocks in the study area (R. B. Taylor, personal communication). The oldest intrusive rocks are of the same approximate age as the gneiss protolith and occur in the northern part of the area as granodiorite and diorite, and in the upper part of Sand Creek as granodiorite. Precambrian intrusive rocks of the 1.7-b.y.-age group include tonalite and metadiorite in the southern part of the study area and a granodiorite mass exposed along Rito Alto Creek in the central part of the study area. A body of quartz monzonite east of Crestone is the youngest Precambrian intrusive rock in the study area, apparently belonging to the 1.45-b.y.-age group.

PALEOZOIC SEDIMENTARY ROCKS

Lower Paleozoic sedimentary rocks, totaling less than 400 feet in thickness, occur in scattered places in the northern part of the study area (Gableman, 1952). These rocks include the Lower Ordovician Manitou Limestone, Middle Ordovician Harding Sandstone, and Upper Ordovician Fremont Dolomite; the Mississippian(?) to Upper Devonian Chaffee Group; and the Lower Mississippian Leadville Limestone.

Much of the central and eastern parts of the study area are composed of upper Paleozoic units, including the Permian and Pennsylvanian Sangre de Cristo, Middle Pennsylvanian Minturn, and Middle and Lower Pennsylvanian Belden Formations. These rocks are composed principally of arkose, sandstone, or shale and total some 12,000 feet in thickness (Johnson and others, 1984a). Parts of the Sangre de Cristo Formation include clasts of fennitized rock and nephelinite believed to be derived from a large, concealed Cambrian(?) alkaline intrusive complex located somewhere west or southwest of the study area (R. B. Taylor, personal communication).

Younger sedimentary rocks do not comprise a significant proportion of the study area, but can be found along the boundaries and outside the area.

TERTIARY IGNEOUS ROCKS

Tertiary plutonic rocks comprise two small stocks of Tertiary age, the Rito Alto and Slide Rock Mountain stocks, which occur in the north-central part of the area. Both stocks are near-surface features, and several andesitic to rhyolitic dikes in the area are apparently related to these or similar unexposed stocks (Toulmin, 1953).

STRUCTURAL SETTING

The major structural features of the study area are Laramide thrusts and late Oligocene to Holocene normal faults (Karig, 1963; Koch, 1963; Litsey, 1958; Nolting, 1970; Scott and Taylor, 1974). The Laramide faulting produced a series of northwest-trending structures with mostly west-dipping surfaces.

Extensional tectonics in Oligocene time produced the present day Sangre de Cristo Mountains and the San Luis and Wet Mountain valleys. The Sangre de Cristo Mountains in the study area are bounded by two large normal faults, the Sangre de Cristo fault along much of the west side of the range and the Alvarado fault along the northern part of the east side of the range, related to this period of extensional tectonics. Faulting is still active in the San Luis valley (Scott, 1970) but may have ceased in the Wet Mountain valley.

METALLIC MINERAL DEPOSITS

WITHIN THE STUDY AREA

Few reports have been published regarding metallic mineral deposits within the study area. Bagg (1908) described copper deposits in sandstone near Rito Alto Peak, Gableman (1953) defined a mineral belt in south-central Colorado, including brief descriptions of several small deposits in the study area, and Toulmin (1953) described molybdenum mineralization associated with the Rito Alto stock.

Metallic mineral deposits which have been studied in recent years within the study area include uranium and copper from redbed-type occurrences, molybdenum from the Rito Alto stock, and copper and gold from vein deposits. There are no mines with significant mineral production within the study area (Johnson and others, 1984a).

OUTSIDE THE STUDY AREA

Metallic mineral deposits which occur adjacent to or within a few miles of the study area include iron from replacement of lower Paleozoic sedimentary rocks at the Orient mine (Stone, 1934; Nolting, 1970), Precambrian stratabound Cu-Pb-Zn-Au-Ag deposits such as those that occur near Sedalia, Colorado, tungsten-bearing veins such as those at Cleora, Colorado, and base- and precious-metal vein systems related to Tertiary igneous activity such as at Silvercliffe, Colorado. Other deposit types which occur in nearby areas in rocks similar to those found in the study area include porphyry-metal deposits and Pb-Zn-Ag replacement deposits of lower Paleozoic sedimentary rocks.

GEOCHEMISTRY

Samples collected for trace-element analysis involved two studies, a pilot study and a regional-scale study. In the pilot study, conducted during May and June 1982, 20 samples were collected for each of three different media: minus-80 mesh (0.180 mm) stream sediments, heavy-mineral-concentrates, and rocks. The sampling, preparation, analytical methods, and data for the pilot study samples are discussed in Zimbelman and others (1983). After selection of optimum sample media in the pilot study a regional-scale trace-element geochemical survey was performed during July 1982.

Composite stream-sediment samples were collected within or adjacent to the study area at first- and second-order drainages as shown on 1:24,000-scale topographic maps. Approximately 2 kg of sediment was collected, air-dried, and then sieved through a 180-micron sieve. The coarse fraction was then discarded and the fines saved for analysis.

Each sample was analyzed for 31 elements using a semiquantitative six-step, direct-current arc, optical-emission spectrographic method (Grimes and Marranzino, 1968). Additional wet-chemical analyses were used to determine As, Sb, Bi, Cd, and Zn at lower levels than possible by the spectrographic method. These samples were analyzed by using a modification of the atomic absorption spectrometry technique described by Viets (1978).

Heavy-mineral-concentrate samples were collected within or adjacent to the study area at sites that are usually also the location of stream-sediment samples. The heavy-mineral-concentrate samples were panned in the field, whenever possible, then air-dried. At the laboratory, the highly magnetic material was removed by a magnet and any light-weight material was removed by allowing the heavier fraction to settle through bromoform (specific gravity 2.82). The heavy-mineral fraction was then separated into a magnetic and a nonmagnetic fraction using a Frantz Isodynamic Separator at a setting of 0.6 ampere, with 15° forward and 15° side settings. The nonmagnetic fraction was pulverized in an agate mortar before analysis. The heavy-mineral-concentrate samples were analyzed for 31 elements by the same spectrographic methods described above.

Rock samples were collected from within or adjacent to the study area to represent either mineralized rock or unusual rock types not characteristic of the most voluminous rock in any particular area such as dikes, veins, or visibly stained rocks. Rock samples were taken from unweathered outcrops wherever possible, ground to minus-200 mesh with a vertical pulverizer, and analyzed for 31 elements using the six-step semiquantitative spectrographic method described above.

The data and the sampling, preparation, and analytical methods for each of these media are discussed in Adrian and others (1984).

DETERMINATION OF THRESHOLD AND ANOMALOUS LEVELS

Throughout this report the term anomalous is used to refer to samples which contain a greater abundance of an element than its threshold value. The threshold value for each element was defined after visual inspection of the frequency distributions (which are included with the element distributions shown on figures 2-13). The geochemical discussion presented below interprets many of the trace-element anomalies in terms of two metallic mineral deposit types that have either not been recognized in the study area (Precambrian stratabound deposits) or are poorly understood at this time (metallization along fractured rock). A brief introduction to these occurrence types is provided below.

Precambrian stratabound deposits

Precambrian rocks in the mountain province of Colorado, northern New Mexico, and southern Wyoming have long been known to contain anomalous concentrations of copper, lead, zinc, silver, gold, and tungsten (e.g., Tweto, 1960; Tweto, 1968; Giles, 1974; Sheridan and Raymond, 1977; Moench and Erickson, 1980; Drobeck, 1979; Heinrich, 1981; and Sheridan and Raymond, 1984). In general, these stratabound occurrences are found associated with calc-silicate or, less frequently, amphibolite lenses or pods within gneiss of the 1.7-b.y.-age group (Tweto, 1960; Sheridan and Raymond, 1977). The stratabound deposits are distributed regionally, but any single occurrence is generally of limited extent, and thus of limited economic importance. However, it is believed that this type of deposit may be important in terms of explaining trace-element anomaly patterns such as those described in this paper.

The scientific study and understanding of Precambrian stratabound deposits in this area is relatively limited because of several factors, including: the deposits are often very small and of limited economic significance, the deposits are usually discontinuous and thus hard to study, and the deposits are often inconspicuous and thus hard to recognize. Studies of these deposits that have included trace-element data include Tweto (1960), who found anomalous amounts of W, Mo, Cu, Zn, Mn, F, P, S, and C and less consistent but anomalous amounts of Ag, Ba, Be, Bi, and Sn from scheelite deposits in Colorado and southern Wyoming and Sheridan and others (1981), who reported anomalous amounts of Zn, Cu, As, and Pb with less frequent but anomalous amounts of Au, Ag, Mo, and Sn from stratabound occurrences in the Gunnison region, Colorado.

In summary, Precambrian stratabound deposits occur regionally throughout the mountain province of Colorado and parts of Wyoming and New Mexico. The study area contains rocks of similar lithologic composition, age, and metamorphic grade as those hosting this type of deposit in surrounding areas. However, this type of deposit has not been identified in the study area, possibly because of the inconspicuous nature of this deposit type and its ore minerals.

Metallization along fractured rock

Found throughout the study area are geochemical anomalies apparently related to iron- and (or) manganese-stained, fractured rock. The zones of fractured rock contain significant geochemical anomalies that are hard to explain geologically. Tweto and others (1970) attribute similar features in the Gore Range, Colorado, to "metal-bearing solutions that diffused into fault systems in small quantities from great depth." Furthermore, these workers found no geologic (including intrusive bodies and altered rock) or magnetic evidence for a local source of the metal-bearing solutions. The geochemical anomalies in rock and stream-sediment samples from the Gore Range, Colorado, included the elements copper, lead, zinc, gold, silver, molybdenum, bismuth, arsenic, antimony, cadmium, mercury, and tin (Tweto and others, 1970). Another example of anomalous trace-element abundances in fractured rock, with no other apparent mineralizing features present, is a study of the Pequop Mountains, Nevada (Erickson and others, 1966). These workers found anomalously high values of zinc, lead, mercury, and silver in oxidized iron-rich fracture filling and small gossan pods.

ARRANGEMENT OF THE GEOCHEMICAL DISCUSSIONS

Throughout this report, the discussions of the trace-element distributions are arranged such that an introductory paragraph explains all of the interpreted geologic sources and their locations for any particular element followed by a more detailed definition and discussion of clusters of anomalous samples for each particular element. The clusters of anomalous samples are outlined in figures 2 through 6 for stream-sediment samples and in figures 7 through 12 for heavy-mineral-concentrate samples.

STREAM-SEDIMENT GEOCHEMISTRY

In general, the trace-element stream-sediment data are best interpreted in terms of background lithogeochemistry most applicable to petrogenetic, structural, or geologic provenance studies rather than mineralizing processes. For example, from a population of 767 samples, the number of samples which occur at levels greater than the spectrographic detection limits for selected elements include: Ag-6; As-0; Au-0; Bi-1; Cd-0; Mo-20; Sb-0; Sn-4; and W-1. Therefore, additional data for As, Zn, Cd, Bi, and Sb were obtained by atomic absorption techniques for the stream-sediment samples.

Copper in stream-sediment samples

Anomalous copper is interpreted to be related to a variety of sources in the study area. These include possible stratabound sulfide mineralization in Precambrian gneiss in the northern part of the area; quartz-veining and (or) seepage along fractured-rock mineralization throughout much of the area; replacement of lower Paleozoic sedimentary rocks in the northern part of the area; the Rito Alto stock in the Cottonwood Peak vicinity; and U-Cu redbed mineralization throughout much of the central part of the area.

Figure 2 shows the distribution of copper in stream-sediment samples. Samples which contain 70 ppm or more copper are referred to as anomalous. This corresponds to 100 samples or the approximate upper 13 percent of the stream-sediment population.

Anomalous copper in area Cu-1 is apparently related to either possible stratabound metal occurrences in Precambrian gneiss, metallization along fractured rock, veining along the Sangre de Cristo fault system, or a combination of these sources.

Anomalous copper in area Cu-2 may be related to a variety of sources. These include replacement of lower Paleozoic sedimentary rocks, especially carbonates, veining and (or) metallization along fractured rock, stratabound metal occurrences in Precambrian gneiss, or any combination of these sources.

Anomalous copper in area Cu-3 is apparently related to the Rito Alto stock and its associated metallization.

Anomalous copper in area Cu-4 is not readily explainable. It is probably related to either high background values in Precambrian gneiss or U-Cu redbed occurrences, or both.

Anomalous copper in area Cu-5 may be due to metallization along fractured rock or to anomalous copper in the Sangre de Cristo Formation. The area does not contain anomalous concentrations of other elements commonly associated with fracture-controlled anomalous areas, and therefore the second explanation is favored.

Anomalous copper in area Cu-6 probably is related to veining and (or) metallization along fractured rock in the Blanca Peak vicinity.

Anomalous copper in areas Cu-7 are related either to metallization along fractured rock, U-Cu redbed occurrences, or a combination of these sources.

Lead in stream-sediment samples

Anomalous lead is interpreted to be related to a variety of sources including: quartz-veining in, and possibly replacement of, lower Paleozoic carbonate rocks and (or) stratabound sulfide occurrences in Precambrian rocks in the Bushnell Peak area; U-Cu redbed occurrences in the central part of the area; quartz-vein mineralizaiton in the Blanca Peak area; and fracture-controlled seepage and (or) quartz-veining along parts of the Sangre de Cristo fault system.

Figure 3 shows the distribution of lead in stream-sediment samples. Samples which contain 70 ppm or more lead are considered anomalous. This corresponds to 58 samples or the approximate upper 8 percent of the stream-sediment population.

Anomalous lead in area Pb-1 closely parallels the outcrop of lower Paleozoic sedimentary rocks. This correlation and the known occurrence of galena-bearing veins in the vicinity of Galena Peak suggests that much of the lead is from veins in the lower Paleozoic units. Two other sources may have contributed to the lead anomaly distribution pattern in this area. These are replacement deposits in lower Paleozoic sedimentary rocks (especially carbonates) and (or) stratabound metal occurrences in Precambrian gneiss. Neither type of mineralization has been identified in this part of the study area to date, although both occur in nearby areas in rocks very similar to those found in the study area.

Anomalous lead in area Pb-2 is apparently related to quartz-veining and (or) metallization along fractured rock.

Anomalous lead in area Pb-3 closely parallels the northern two-thirds of the known outcrop of U-Cu redbed occurrences. Although this area contains many anomalous samples, none of the samples exceed 100 ppm lead.

Area Pb-4 contains three samples which are anomalous in lead. All three samples are located within close proximity to the Sangre de Cristo fault system and are probably related to either quartz-veining or metallization along fractured rock localized by this system.

Anomalous lead in area Pb-5 is probably related to either U-Cu redbed occurrences, metallization along fractured rock, or a combination of these sources.

Anomalous lead in area Pb-6 is probably related to quartz-vein mineralization in the Blanca Peak area.

Four samples (areas Pb-7) are not part of any large cluster of samples which contain anomalous lead. These samples are downstream from areas of faulting and may represent either metallization along faults or fractures or quartz-veining associated with the structures.

Zinc in stream-sediment samples

Anomalous zinc is apparently related to a variety of sources in the study area including: possible Precambrian-hosted stratabound sulfide occurrences in the northern part of the area; U-Cu redbed occurrences in the central part of the area; quartz-veining and (or) seepage along fractured rock in the southern part of the area; and unknown, probably background related occurrences in the south-central part of the area. Replacement of lower Paleozoic sedimentary rocks in the northern part of the study area and vein and (or) seepage mineralization throughout much of the study area may also be responsible for some of the zinc anomalies.

Figure 4 shows the distribution of zinc in stream-sediment samples. Samples which contain 100 ppm or more zinc are referred to as anomalous. This corresponds to 96 samples or the approximate upper 13 percent of the population.

Anomalous zinc in area Zn-1 closely overlaps both an area of Precambrian gneiss that is believed favorable for stratabound metal occurrences (R. B. Taylor, personal communication) and lower Paleozoic sedimentary rocks, including carbonates. The anomalous zinc could be related to either the stratabound metal occurrences, quartz-veining and (or) metallization along fractures in either rock type, or possible replacement deposits in the lower Paleozoic rocks.

Anomalous zinc in areas Zn-2 and Zn-3 closely correlates with the northern and southern parts, respectively, of U-Cu redbed occurrences. The zinc anomalies are apparently related to this type of mineral deposit.

Anomalous zinc in area Zn-4 is not readily explainable. Because of the paucity of anomalies of other hydrothermal-related elements in this area, the source is believed to be lithologically controlled and not related to any metallizing processes.

Anomalous zinc in area Zn-5 is related to quartz-veining and (or) metallization along fractures in the vicinity of Blanca Peak.

Scattered zinc anomalies not related to any of the above-mentioned patterns occur in several areas which contain known faults (areas Zn-6). These anomalies are probably related to nearby faults, representing either metallization along the faults or quartz-veining controlled by the structures.

Cadmium in stream-sediment samples

Anomalous cadmium is related to U-Cu redbed mineralization in the central part of the study area, the Rito Alto stock in the Cottonwood Peak vicinity, possible stratabound sulfide occurrences in Precambrian gneiss in the northern part of the area, and quartz-veining and (or) seepage along fractured rock mineralization throughout much of the area.

Figure 5 shows the distribution of cadmium in stream-sediment samples. Samples which contain 0.4 ppm or more cadmium are referred to as anomalous. This includes 105 samples or the approximate upper 14 percent of the stream-sediment population.

Anomalous cadmium in area Cd-1 is probably related to either stratabound metal occurrences in Precambrian gneiss, metallization along fractured rock, or a combination of these sources.

Anomalous cadmium in area Cd-2 is related to a variety of sources. In the northern part of area Cd-2, the cadmium is probably related to either stratabound metal occurrences in Precambrian gneiss, quartz-veining and (or) metallization along fractures, replacement of lower Paleozoic sedimentary rocks, or a combination of these sources.

In area Cd-3 anomalous cadmium is related to the Rito Alto stock.

Anomalous cadmium in area Cd-4 closely parallels the known occurrence of U-Cu redbed deposits in upper Paleozoic sedimentary rocks. Some of the anomalies in area Cd-4 may also be due to seepage along fractured rock and (or) quartz-vein type mineralization.

Anomalous cadmium in area Cd-5 is apparently related to quartz-veining and (or) metallization along fractured rock.

Arsenic in stream-sediment samples

Most of the anomalous arsenic in the area is related to U-Cu redbed mineralization in the central part of the study area. Anomalous arsenic in the upper part of Sand Creek is probably also related to U-Cu redbed mineralization or, alternatively, to high background levels in Precambrian granodiorite in this area. Scattered samples, generally around the edge of the mountain range, contain anomalous arsenic which is probably related to either seepage along fractured rock and (or) quartz-veining controlled by faults.

Figure 6 shows the distribution of arsenic in stream-sediment samples. Samples which contain 5 ppm or more arsenic are referred to as anomalous. This corresponds to 28 samples or the approximate upper 4 percent of the stream-sediment population.

Samples containing anomalous amounts of arsenic in area As-1 correspond closely to the central part of the U-Cu redbed deposits. The arsenic is apparently related to the U-Cu mineralization.

Anomalous arsenic in area As-2 consists of six samples in the uppermost part of Sand Creek. This arsenic could be coming either from U-Cu redbed occurrences in the uppermost part of the drainage, or from a high background level in Precambrian granodiorite in the upper part of the drainage.

Six scattered samples in the northern part of the study area contain anomalous arsenic (areas As-3). All of these samples are near the edge of the Sangre de Cristo Mountain range and are probably related to either metallization along various fault systems or quartz-veining localized along these structures.

Summary of stream-sediment geochemistry

The northern part of the study area contains anomalous amounts of Cu, Pb, Zn, and Cd in stream-sediment samples. These metals are probably related to a number of processes, including quartz-veining, seepage along fractured rock, replacement of lower Paleozoic rocks, and possible stratabound metal deposits in Precambrian rocks.

Stream-sediment samples draining the Rito Alto stock, near Cottonwood Peak, are anomalous in Cu and Cd.

Much of the central part of the study area contains stream-sediment samples anomalous in one or more of the elements Cu, Pb, Zn, As, and Cd. These metals are related to U-Cu redbed occurrences in this part of the study area.

Throughout much of the study area, and including the Sangre de Cristo fault system, the Alvarado fault system, and a northwest-trending fault system near Blanca Peak, quartz-vein mineralization and seepage along fractured rock has produced anomalous abundances of Cu, Pb, Zn, As, and Cd in stream-sediment samples.

An area south of Medano Pass contains anomalous amounts of Zn in stream-sediment samples. These anomalies may be due to a high background level of Zn in Precambrian gneiss, veining or seepage along fractured rock, or, possibly, stratabound metal occurrences in the gneiss.

HEAVY-MINERAL-CONCENTRATE SAMPLES

Heavy-mineral-concentrate samples are subsamples of stream sediments. The heavy-mineral-concentrate samples were collected at most of the same sites as the stream-sediment samples, panned in the field whenever possible with a standard gold pan, and separated into a nonmagnetic heavy-mineral fraction in the laboratory (Adrian and others, 1984). This process selectively concentrates many ore-related elements in the heavy-mineral-concentrate samples and reduces the influence of many background minerals which can dilute or mask ore-related mineral abundances.

Copper in heavy-mineral concentrates

A number of sources are responsible for producing anomalous copper values throughout the study area. The exact proportion any particular source is contributing in any part of the area is not known with a great degree of certainty. However, it is felt that in the northernmost part of the area the copper anomalies are most likely related to scattered, unidentifiable sulfide deposits in Precambrian gneiss. Near Galena Peak and in the lower Paleozoic carbonate rocks in general, copper values are related to replacement deposits and (or) veining. Near Cottonwood Peak, scattered copper anomalies are related to porphyry-type mineralization associated with the Rito Alto stock. South of Cottonwood Peak, near the crest of the range, many copper anomalies are related to U-Cu redbed mineralization in upper Paleozoic clastic sedimentary rocks. In the southern part of the area copper anomalies are related to a strongly developed vein system associated with a northwest-trending fault system in the vicinity of Blanca Peak. Throughout much of the range, especially near the foot of the range, scattered copper anomalies are related to quartz-veining and (or) seepage along fractured rock.

Figure 7 shows the distribution of copper in heavy-mineral-concentrate samples. Samples containing 100 ppm or more copper are considered to be anomalous. This corresponds to 83 samples representing the upper 11 percent of the concentrate population.

Seven samples in the northern part of the study area (area Cu-8) contain anomalous copper which is most easily interpreted as originating from either stratabound metal occurrences in Precambrian gneiss, metallization along fractures, or a combination of these sources.

Thirty-five samples contain anomalous copper in an irregularly shaped area which closely mimics the outcrop of lower Paleozoic sedimentary rocks between West Creek and Steel Canyon (area Cu-9). This area contains one of the highest densities of samples containing anomalous copper in the study area. The anomalies are probably related to one of two sources: (1) replacement deposits in carbonate-bearing lower Paleozoic rocks, or (2) veins or fracture-controlled metallization in a variety of rock types in the area.

A few scattered occurrences of anomalous copper center around the Rito Alto stock (area Cu-10). These anomalies are probably related to the stock and its associated metallization.

Scattered occurrences of anomalous copper occur from the upper part of Cotton Creek south to South Colony and Cottonwood Creeks (area Cu-11). These occurrences are probably related to scattered U-Cu redbed lenses which occur in the uppermost part of the Minturn Formation and the lowermost part of the Sangre de Cristo Formation. These anomalous samples are generally within 2-3 miles downstream of the outcrop of the Minturn and Sangre de Cristo contact and are considered to be a good pathfinder for U-Cu redbed mineralization.

Six anomalous copper values in the lower parts of Pole, Sand, Cottonwood, South Crestone, and Cold Creeks (area Cu-12) are apparently related to metallization along fractured rock and (or) vein mineralization along a northwest-trending fault system in Precambrian gneiss.

Five samples contain anomalous copper in the upper parts of Cottonwood, North Muddy, Medano, and Bruff Creeks (area Cu-13). Possible sources include U-Cu redbed occurrences in upper Paleozoic sedimentary rocks and either veining or metallization along fractured rock. Neither type of mineralization has been identified in the area.

Anomalous copper values in the Blanca Peak area (area Cu-14) center on the fault-controlled vein system near Blanca Peak. Two samples from the South Fork of the Huerfano River also contain anomalous copper. The source for these copper anomalies is probably the extensive vein system associated with the northwest-trending fault system in the vicinity of Blanca Peak. However, contribution from scattered occurrences of disseminated chalcopyrite in Precambrian metadiorite is also possible.

Lead in heavy-mineral concentrates

Numerous sources appear likely to have produced lead anomalies in the heavy-mineral-concentrate samples. These include possible Precambrian stratabound sulfide deposits in the northern part of the study area, veins and (or) possible replacement deposits in lower Paleozoic sedimentary rocks in the north-central part of the area, redbed associated occurrences throughout much of the central part of the area, metallization associated with the Rito Alto Stock in the Cottonwood Peak vicinity, and scattered vein and (or) fracture-related seepage deposits, including those in the Blanca Peak area, throughout much of the length of the Sangre de Cristo fault system, and parts of the Alvarado fault system.

Figure 8 shows the distribution of lead in heavy-mineral-concentrate samples. Samples which contain 200 ppm or more lead are referred to as anomalous. This corresponds to 84 samples representing the upper 12 percent of the population.

In general, the distribution of samples containing anomalous lead is less clustered than many of the other elements discussed in this report. Lead anomalies occur in several small clusters throughout a larger portion of the study area.

Area Pb-8 includes an approximately circular area containing many samples anomalous in lead. This area closely outlines a sillimanite gneiss complex (R. B. Taylor, personal communication) which may contain Precambrian stratabound metal deposits. The lead anomalies in this area may be related to either the postulated stratabound metal bodies, high local background lead values in a unit or units of Precambrian gneiss, concentration of metals along fractures, or any combination of these sources.

Area Pb-9 contains anomalous lead which is probably related to either Precambrian stratabound sulfide deposits in the uppermost parts of the drainages, vein and (or) replacement deposits in lower Paleozoic sedimentary rocks, or a combination of these occurrence types.

Area Pb-10 contains one of the most densely clustered areas of anomalous lead in the study area along with some of the highest lead values (greater than 20,000 ppm). The lead in area Pb-10 is probably derived from metallization along fractures and (or) vein type mineralization associated with the Sangre de Cristo fault system.

Area Pb-11 contains four samples with anomalous lead values. The lead in this area is apparently related to metallization associated with the Rito Alto stock.

Anomalous lead in area Pb-12 is apparently related to metallization along fractures and (or) vein type mineralization associated with the Sangre de Cristo fault system.

Lead anomalies in areas Pb-13 are apparently related to U-Cu redbed occurrences in upper Paleozoic sedimentary rocks. This source could also be complemented with lead derived from metallization along various faults upstream from any of the anomalous samples.

Area Pb-14 contains many lead anomalies confined to the lowermost parts of their respective drainages. Two sources seem possible for the lead, U-Cu redbed deposits and (or) metallization along fractures. The latter source is favored for having provided most of the lead because of the lack of lead in drainages immediately below known redbed occurrences and the proximity of the Alvarado fault system to the anomalies.

Scattered lead anomalies in areas Pb-15 are probably related to metallization along fractures and (or) vein mineralization associated with the Sangre de Cristo fault system.

Anomalous lead in area Pb-16 is related to Tertiary veining and (or) seepage along fractures in the Blanca Peak area.

Lead anomalies in scattered, relatively isolated occurrences (areas Pb-17) are probably related to veining or metallization along fractured rock located near the edges of the mountain range and associated with the range front fault systems.

Barium in heavy-mineral concentrates

Most of the samples containing anomalous amounts of barium occur north of latitude 38°. Three sources appear most likely for explaining the anomalous barium: possible Precambrian-hosted stratabound sulfide occurrences in the northern part of the study area, high background levels in either or both of the Minturn and (or) Belden Formations, and seepage along regional-scale faults. Barium derived from igneous activity related to either of two Tertiary stocks in this area may have also contributed to the anomaly distributions, as might have barium derived from U-Cu redbed occurrences in upper Paleozoic sedimentary rocks.

Figure 9 shows the distribution of barium in heavy-mineral-concentrate samples. Samples which contain 5,000 ppm or more barium are referred to as anomalous. This corresponds to 86 samples representing the upper 12 percent of the concentrate population.

Anomalous barium occurrences are generally confined to the northern half of the study area. The northernmost area of anomalous barium forms a semicircular pattern approximately 1.2 miles in width (area Ba-1). This area very closely outlines an area of sillimanite gneiss which is thought to be a good potential host for Precambrian stratabound metal deposits (R. B. Taylor, personal communication).

Area Ba-2 contains numerous samples which are anomalous in barium. This area drains upper Paleozoic Minturn and Belden Formations, and also contains the only two Tertiary stocks known in the study area. Area Ba-4 (see discussion below) also contains a similar distribution of samples containing anomalous barium and drains the Minturn and Belden Formations but lacks the Tertiary intrusives. Therefore, it seems most likely that the barium in area Ba-2 is mostly due to background-level barium in these upper Paleozoic rocks, rather than to the intrusive rocks. However, the anomalous barium does form distinct patterns apparently centered around the Slide Rock stock and peripheral to the Rito Alto stock. The possibility that these rocks were responsible either for the deposition of barium or the mobilization of barium which was originally in the sedimentary rocks cannot be entirely discounted.

Area Ba-3 contains a few scattered samples that contain anomalous amounts of barium. Two sources appear to be likely candidates for the barium, high background levels in upper Paleozoic sedimentary rocks which occur in the uppermost parts of the drainages or seepage from factures along the range front faults. A combination of these processes could also produce the anomalies.

Area Ba-4 contains the largest number of samples that contain anomalous barium in the study area. This area closely parallels both the occurrence of U-Cu redbed concentrations and the outcrop of the Minturn and Belden Formations. It seems most likely that the barium distribution in area Ba-4 is due to a high background level of barium in either or both of the Minturn and the Belden Formations. This is because most of the barium anomalies (and the outcroppings of these formations) occur on the east side of the ridge crest, whereas much of the U-Cu redbed deposits occur on both the west and east sides of the crest. The northwesternmost part of area Ba-4 includes rocks intensely faulted by the Sangre de Cristo fault system, and the barium anomalies in this area could be from mineralization related to this fault system.

Five samples in the vicinity of North Brush and Spruce Creeks (area Ba-5) contain anomalous barium. These samples are near the Alvarado fault zone and are probably related to veining along this zone.

Only a few scattered occurrences of anomalous barium occur south of latitude 38°. These include single point anomalies in Cottonwood, South Muddy, Aspen, and Bruff Creeks. All of these occurrences are near major faults, and contain barium in the lowest 50th percentile upstream from the faults. Therefore, it is reasonable to assume that the barium is coming from metallization along these faults.

Three samples in the upper part of the South Fork of the Huerfano River contain anomalous amounts of barium (area Ba-6). The source of these anomalies is not known as the geologic mapping did not include this area in its study.

Molybdenum in heavy-mineral concentrates

Clusters of samples containing anomalous amounts of molybdenum occur in five areas. The northernmost area contains the highest concentrations of anomalous samples and is probably related to either high background molybdenum values in Precambrian gneiss, anomalous concentrations of molybdenum in Precambrian stratabound sulfide occurrences, seepage along fractured rock, or a combination of these processes. Anomalous molybdenum in the Rito Alto stock area is apparently related to the stock and its associated metallization. Anomalous molybdenum in the central part of the area is not readily explainable. Potential sources in this area include high background levels in Precambrian gneiss or the Sangre de Cristo Formation, concentrations in Precambrian stratabound sulfide occurrences, U-Cu redbed occurrences, fracture-related seepage, or a combination of these processes. Anomalous concentrations of molybdenum in the southern part of the study area are apparently related to veining and (or) seepage along fractured rock. The fault systems which are apparently responsible for localizing the veins and (or) seepages include the northwest-trending fault system in the Blanca Peak area and the range fault system in the southernmost part of the area.

Figure 10 shows the distribution of molybdenum in heavy-mineral-concentrate samples. Samples containing 15 ppm or more molybdenum are referred to as anomalous. This corresponds to 71 samples representing the upper 10 percent of the concentrate population.

The largest cluster of anomalous molybdenum samples is in the northern part of the study area (area Mo-1). The majority of the anomalous samples occur within a 5-mile radius of Bushnell Peak. All of the samples which contain anomalous molybdenum in this area are in drainages which contain Precambrian gneiss, which suggests a relationship between the two. Two potential sources seem most likely: (1) either a high background level in the gneiss, possibly a particular unit of the gneiss, or (2) stratabound metal occurrences in the gneiss, or both. Metallization along fractures and veining in the gneiss could also contribute to the molybdenum anomalies.

Area Mo-2 contains three samples which have anomalous values of molybdenum. These three samples are all in the uppermost parts of streams draining the Rito Alto stock. The stock, which has been prospected for molybdenum mineralization, is apparently responsible for these molybdenum values.

Numerous, scattered samples contain anomalous molybdenum in the central part of the study area (area Mo-3). The source of this molybdenum is not clear. Potential contributors include high background levels in either or both the Precambrian gneiss or the Sangre de Cristo Formation, concentration along fractures, U-Cu occurrences in upper Paleozoic sedimentary rocks, Precambrian stratabound metal occurrences, or any combination of these sources.

Samples containing anomalous amounts of molybdenum in the Sand and Medano Creeks area (area Mo-4) occur in various rock types which are cut by a series of northwest-trending faults. The molybdenum is apparently related to metallization along fractured rock.

Anomalous molybdenum in the southern part of the study area (area Mo-5) is probably due to veining and (or) metallization along the northwest-trending fault system in the Blanca Peak area.

Additional molybdenum anomalies occur in Axtel Canyon and Zapata Creek and are probably related to the range front fault system in this part of the study area.

Tungsten in heavy-mineral concentrates

Three areas contain clusters of anomalous tungsten which are readily explainable. These include possible Precambrian stratabound sulfide occurrences in the northern part of the area, occurrences related to the Rito Alto stock in the vicinity of Cottonwood Peak, and veining and (or) fracture-related seepage in the southern part of the study area. In addition, numerous occurrences of scattered, isolated tungsten anomalies are not as easily explained. The source for these anomalies is not known, but probably includes either high background levels in certain rock unit(s), which may not necessarily be differentiated on the geologic map, or vein or fracture-related mineralization.

Figure 11 shows the distribution of tungsten in heavy-mineral-concentrate samples. Samples which contain 150 ppm or more tungsten are referred to as anomalous. This corresponds to 89 samples representing the upper 12 percent of the heavy-mineral-concentrate population.

The greatest concentration of samples containing anomalous amounts of tungsten is in the northern part of the study area, centered around Bushnell Peak (area W-1). Approximately 35 samples contain anomalous amounts of tungsten in this area; many contain 500 ppm or more tungsten. There is a close association between samples containing anomalous tungsten and the occurrence of sillimanite-bearing Precambrian gneiss (R. B. Taylor, personal communication). This association suggests the possibility of a genetic relationship between the Precambrian gneiss and the anomalous tungsten values. Aphanitic scheelite was identified in several samples studied with a binocular microscope, suggesting the presence of pods or lenses of scheelite-bearing rock in the Precambrian gneiss of this area.

Many of the heavy-mineral-concentrate samples in the uppermost parts of drainages peripheral to the Rito Alto stock contain anomalous tungsten (area W-2). These anomalies are probably related to the stock either as high background values in certain phases or related to metallizing processes.

Area W-3 contains three samples with anomalous amounts of tungsten. These anomalies are apparently related to vein- or fracture-controlled metallization associated with the Sangre de Cristo fault system.

Anomalous tungsten in area W-4 is apparently related to veining or metallization associated with fractured rock in the vicinity of Blanca Peak and along the range front in this area.

Area W-5 contains five samples which are anomalous in tungsten whose source is not readily explainable. Two explanations, however, seem most likely: (1) the tungsten is related to a high background level in Precambrian gneiss in this particular area, or (2) the tungsten is related to seepage along faulted rock. The first explanation is favored because of the consistency of the values, that is, there is no tailing off of the values downstream from any faults, and because of the relatively low values of the tungsten anomalies (200 ppm or less).

Anomalous tungsten in areas W-6 is characterized by relatively isolated, single "spot" anomalies which are not readily explainable. Sources which may have contributed to these anomalies include high background tungsten in a variety of rock units, veining or metallization in fractured rock, especially along the range-front fault systems, or a combination of these sources.

Tin in heavy-mineral concentrates

Tin anomalies are apparently related to several possible sources in the study area. In the northern part of the area a high concentration of anomalous tin is closely related to Precambrian gneiss and apparently represents either a very high background level in this rock or some particular unit(s) of the rock, anomalous concentration of tin in unidentified Precambrian stratabound sulfide occurrences, concentration of tin along faults and (or) fractures, or a combination of these processes. In the Cottonwood Peak area anomalous tin is apparently associated with the Rito Alto stock. In the central and south-central parts of the study area many samples contain 70-100 ppm tin and are apparently related to high background levels in Precambrian gneiss or unit(s) of the gneiss. Throughout the study area, and including the Blanca Peak area, scattered tin anomalies are associated with fault or vein-type mineralization. This type of tin localization is most prominent along either the range-front fault systems or in the quartz-vein mineralizing systems such as that found in the Blanca Peak area.

Figure 12 shows the distribution of tin in heavy-mineral-concentrate samples. Samples which contain 70 ppm or more tin will be referred to as anomalous. This corresponds to 108 samples representing the upper 15 percent of the concentrate population.

The largest cluster of samples containing anomalous amounts of tin, and some of the highest tin values in the area, is in the northern part of the study area (area Sn-1). This area is within a 5- to 6-mile radius of Hunts Peak. Almost all of the anomalous samples are from drainages which contain Precambrian gneiss, suggesting that the tin occurs either as anomalously high background levels in certain units of the gneiss, or as pods or lenses associated with possible stratabound metal deposits in the Precambrian gneiss. The tin, or some of the tin, may have also originated from metallization along faults or fractures in this area.

Anomalous tin occurs peripheral to the Rito Alto stock in area Sn-2. These tin anomalies are probably related to the Rito Alto stock and its associated metallization or background levels. However, the very high tin value (greater than 1,000 ppm) in Orient Canyon is probably related to either metallization associated with fractured rock or vein-type mineralization.

Scattered occurrences of anomalous tin occur along the eastern part of the study area from Spruce Creek to Goodwin Creek (areas Sn-3). Possible sources for this tin include high background concentrations in the Sangre de Cristo Formation and metallization along northwest-trending fault and fracture zones which bound the east edge of the range.

Many samples between Burnt Gulch and Rito Oso Creek (area Sn-4) contain anomalous tin values. Most of the values are either 70 or 100 ppm and are from drainages which contain Precambrian gneiss. Because of the close association of the anomalies with this one rock type, the relative low value of the tin anomalies, and the lack of anomalous occurrences of other elements in this area, this cluster of tin anomalies is interpreted to represent high background tin values in some unidentified unit(s) of the gneiss. Exceptions to the above-mentioned generalization are a few samples in this area which contain more than 100 ppm tin. Most of these samples are close to, but downstream from, northwest-trending faults and may represent metallization along these structures.

In the southern part of the study area three samples contain anomalous tin (area Sn-5). Two of these samples are in the upper part of the Huerfano River and probably represent quartz-vein mineralization near Blanca Peak. One tin anomaly near Chokecherry Gulch is probably related to tin concentration along the range-front fault in this area.

Gold, bismuth, and zinc in heavy-mineral concentrates

Figure 13 shows the distribution of detectable gold, bismuth, and zinc in heavy-mineral-concentrate samples.

Gold was detected at a level of 200 ppm or more in two concentrate samples. The northern sample is located in Precambrian metavolcanic sedimentary rocks in Howard Creek. The source of the gold is not known, although possible stratabound metal occurrences in Precambrian gneiss and quartz-veining or metallization along fractured rock seem most likely. The second sample containing anomalous gold is located in Big Cottonwood Creek. This sample is located in upper Paleozoic sedimentary rocks approximately 3 miles downstream from their contact with the Rito Alto stock. The source for the gold in this sample may be veining or metallization along fractures, and may possibly be related to the Rito Alto stock.

Bismuth occurs in abundances of 20 ppm or more in 18 concentrate samples. All but three of these sample sites are located north of Galena Peak. The samples were all collected from drainages containing Precambrian gneiss, and the bismuth is thought to be related to either the gneiss (as either a background feature or in possible stratabound metal occurrences), quartz-veining, metallization along fractures, or a combination of these sources. The source for the bismuth from the three samples south of Galena Peak is not known but may be veining or metallization along fractures.

Zinc occurs in abundances of 500 ppm or more in eight concentrate samples. Five of these samples are located on the east side of the range north of Hamilton Creek. These samples may be related to possible stratabound metal occurrences in Precambrian rocks in the Red Mountain-Bushnell Peak area. Two samples containing anomalous zinc are located near regional-scale faults and are thought to be related to metallization along these faults. These samples are located in Orient Canyon and South Muddy Creek. A single sample containing anomalous zinc in Goodwin Creek may have as its source U-Cu redbed mineralization which is known to exist about 2 miles upstream from the sample location.

Summary of heavy-mineral-concentrate geochemistry

Figure 14 is a summary map of selected trace-element anomalies in heavy-mineral-concentrate samples. It should be remembered that the map represents anomalous stream drainage samples which originated upstream from the collection sites. Therefore, the source(s) of the anomalies may lie an undetermined distance upstream from the areas outlined.

Area A is anomalous in the elements W-Sn-Mo-Cu-Pb-Zn-Ba-Bi and contains a central "barren" zone which is not anomalous in any of these elements. Several sources may have contributed to the anomalous concentrations in this area. These include suspected Precambrian stratabound metal occurrences, anomalously high background levels of any or all of the elements in a particular rock unit(s), quartz veins, metallization along fractured rock, and replacement of lower Paleozoic sedimentary rocks. Of these sources, only quartz-vein mineralization has been identified to date. However, it is thought that the Precambrian stratabound metal type of deposit has a relatively high likelihood for existence. The existence of a carbonate-replacement deposit seems unlikely.

Area B consists of an approximately semicircular area which is anomalous in two or three of the elements Cu, Pb, and Ba. The source(s) for the anomalies may include one or more of the following types of mineralization: quartz-veining, metallization along fractures, U-Cu redbed occurrences in upper Paleozoic sedimentary rocks, replacement of lower Paleozoic sedimentary rocks, and (or) mineralization associated with the Slide Rock stock. Of these mineral deposit types, quartz-veining and metallization along fractured rock seem to be the deposit types which probably account for the majority of the anomalous sample sites, particularly for the eastern and western parts of area B, along the vicinity of the Alvarado and Sangre de Cristo fault systems, respectively. None of the other mineralization types have been recognized to date in the area, yet the geochemical signature is compatible with any of these sources. The potential for metallization associated with the Slide Rock stock (that is, a porphyry-metal type of system) seems to be relatively low due to the paucity of noticeable alteration associated with the exposed part of the stock. Neither replacement in lower Paleozoic carbonate rocks or U-Cu redbed occurrences in upper Paleozoic sedimentary rocks have been identified in area B. Thus, metallization along fractured rock and quartz-veining seem to be the most likely sources for the anomalies.

Area C contains anomalous W-Mo-Sn-Bi-Pb. This area centers on the Rito Alto stock and the anomalous trace-element patterns are probably related to metallization associated with the stock. This is the only known occurrence of porphyry-type metallization in the study area. The Rito Alto stock was studied by Toulmin (1953) and has been explored via several drill holes. Apparently, the metallization associated with the stock is weakly developed, subeconomic, and (or) of limited extent.

Areas D and E are two small areas which contain anomalous trace-element abundances along major structural features, the Sangre de Cristo and Alvarado fault systems. Area D contains a more complex trace-element signature, consisting of W-Sn-Mo-Bi-Pb-Zn. This signature is apparently related to mineralization in lower Paleozoic carbonate rocks, including the Orient iron mine, and in Precambrian gneiss cut by the Sangre de Cristo fault system. Area E contains anomalous Ba and Pb and is centered on the Rita Alta copper mine.

Area F outlines an area that approximately parallels U-Cu redbed-type occurrences in upper Paleozoic sedimentary rocks. Most of area F contains anomalous amounts of one or more of the elements Cu, Pb, and Ba. These elements are apparently related to the U-Cu mineralization and are thought to be good pathfinder elements for this type of mineralization. Two exceptions to this generalization are parts of Cotton and Spring Creeks on the west side of area F which contain anomalous Sn-Pb-Ba and the northeastern part of area F which contains anomalous amounts of Cu-Pb-Zn-Ba-Bi-Sn. The most likely source for the more complex trace-element anomalies in these areas is quartz-veining or metallization along fractures, especially along the major fault systems which are present in both of these areas. It is also possible that Precambrian stratabound metal occurrences contribute some of the metals in these areas.

Area G contains anomalous abundances of Cu-Pb-Sn, with sporadic occurrences of anomalous amounts of Mo, and (or) Zn. The source(s) of the anomalies in area G is not readily explainable. Three sources seem most likely, including unusually high background values of any or all of these elements, probably in a unit or units of Precambrian gneiss, stratabound metal occurrences in Precambrian gneiss, and (or) metallization along fractured rock.

Area H contains anomalous amounts of Ba and (or) Cu. The source for these anomalies is not known because it is outside the study area boundaries and has not received detailed geologic mapping.

Area I contains anomalous amounts of W-Sn-Mo-Cu-Pb. Anomalies in area I are apparently related to a strongly developed quartz-vein system which trends northwesterly and is well exposed on the north face of Blanca Peak. A semicircular area west of Blanca Peak which contains anomalous amounts of copper could be related to disseminated chalcopyrite identified in Precambrian rocks in this area. Also, a small area near the base of the range including Holbrook Creek and Chokecherry and Chimney Gulches contains anomalous W-Sn-Cu and is probably related to metallization associated with a range-front fault.

ROCK GEOCHEMISTRY

Rock samples were generally collected to represent altered or mineralized rocks at mines or prospects, or "different rocks" such as pegmatites, dikes, or stained rocks, and do not represent a thorough or systematic sampling of the study area. Therefore, the rock data should be used in conjunction with the stream-deposit data, and should not be considered comprehensive on its own.

A summary map of selected elements, including Au, Ag, Pb, Zn, Cu, Mo, Ba, Bi, As, Sb, and W, in rock samples is shown on figure 15. A brief discussion of these elements follows.

Gold in rock samples

Gold was found in abundances of 10 ppm or more in six rock samples. Three of the samples are from quartz-vein samples in Precambrian gneiss in the Pole Creek drainage basin. One of the gold-bearing samples is from a quartz vein exposed on the north face of Blanca Peak, one is from a quartz vein in Carr Gulch, and one is from a quartz vein in Precambrian gneiss near Spanish Creek and the Independence Mine.

Silver in rock samples

Silver occurs in abundances of 5 ppm or more in 17 rock samples. Most of the silver-bearing samples are from quartz veins associated with northwest-trending faults. The veins are hosted by a variety of rock types including Precambrian gneiss and metadiorite and upper Paleozoic sedimentary rocks.

Lead in rock samples

Lead occurs in abundances of 200 ppm or more in 12 rock samples. These samples include a wide variety of rock types including Precambrian-hosted pegmatites, Precambrian granodiorite and amphibolite, quartz veins, and lower Paleozoic carbonate rocks. All samples which contain 200 ppm or more lead are located north of Sand Creek.

Zinc in rock samples

Zinc occurs in abundances of 200 ppm or more in 10 rock samples. Anomalous zinc is found in an assortment of rock types in the study area, but is confined to an area north of Taylor Creek. Rock types which contain anomalous zinc include quartz veins, pegmatites, lower Paleozoic carbonates and quartzites, and tonalite from the Rito Alto stock.

Copper in rock samples

Copper occurs in abundances of 500 ppm or more in 34 rock samples. These samples are scattered throughout the study area and are from a variety of rock types, including U-Cu redbed occurrences, quartz veins, Precambrian amphibolite, skarn, and metadiorite, and various rocks associated with the Rito Alto stock.

Molybdenum in rock samples

Molybdenum occurs in abundances of 5 ppm or more in 26 rock samples. The greatest concentration of rock samples containing anomalous amounts of molybdenum is in the Rito Alto stock area. Rock samples from the stock which contain anomalous molybdenum include tonalite, quartz-monzonite, rhyolite, and quartz veins. Other samples containing anomalous molybdenum occur throughout much of the study area, generally in quartz veins located near regional-scale, northwest-trending fault systems.

Barium in rock samples

Barium occurs in abundances of greater than 5,000 ppm in eight rock samples. Four of these samples are located in the Rito Alto stock, three are peripheral to the stock (one at the Rita Alta mine and two in Hot Springs Canyon), and one is in Hayden Pass Creek drainage. The close association between anomalous barium and the Rito Alto stock suggests a genetic relationship between the two.

Other elements in rock samples

Bismuth, arsenic, antimony, and tungsten are included on the rock geochemistry summary map but are not discussed individually. Generally, these elements occur in detectable quantities in a very limited number of samples in the study area and little is known about their relationship with the different types of mineral deposit types found in the area.

Summary of rock geochemistry

Copper and molybdenum are found in a variety of rock types scattered throughout much of the study area. Barium is generally confined to the vicinity of the Rito Alto stock and is thought to be genetically related to the stock. Lead and zinc are found in anomalous amounts in a variety of rock types, but the anomalies are confined to the northern half of the study area. Silver occurs throughout much of the study area, generally in quartz veins associated with northwest-trending structural elements. Gold is confined to quartz veins hosted by Precambrian gneiss and apparently localized by northwest-trending structures.

SUMMARY

The geochemical interpretations presented here are based on stream drainage samples collected from first- and second-order drainages supplemented by scattered rock samples collected mostly at prospect pits and mines.

The area around Bushnell Peak in the northern part of the study area may contain Precambrian stratabound metal occurrences. Although not yet recognized within the study area, this type of deposit does occur in similar rocks in nearby areas. If this type of mineral deposit does exist, it probably occurs as small, discontinuous, scattered lenses and (or) pods. The Bushnell Peak area contains some of the highest values and some of the largest clusters of anomalous samples in the study area, including anomalies in the elements W-Sn-Mo-Cu-Pb-Zn-Ba-Bi in heavy-mineral-concentrate samples and Ag-Pb-Zn-Cu-As-Sb-Bi-Ba-Mo in rock samples.

South of Bushnell Peak, in the vicinity of Cottonwood Peak, metallization associated with the Rito Alto stock produced trace-element anomalies in the elements W-Mo-Sn-Bi-Pb-Ba in heavy-mineral-concentrate samples and Mo-Cu-Pb-Zn-Ba-Bi in rock samples.

Between Cottonwood and Bushnell Peaks, especially near the range fronts, metallization associated with either quartz-veining or fractured rock produced both simple and complex trace-element anomaly signatures in the suite of elements Cu-Pb-Zn-Ba-W-Sn-Mo-Bi in heavy-mineral-concentrate samples and Au-Ag-Ba-Bi-Cu-Pb-Zn in rock samples.

Much of the central part of the study area is characterized by anomalous amounts of one or more of the elements Cu, Pb, and Ba in heavy-mineral-concentrate samples. Anomalous abundances of these elements outline the occurrence of U-Cu redbed mineralization in upper Paleozoic sedimentary rocks.

In the vicinity of Blanca Peak, quartz-vein mineralization associated with a northwest-trending fault system produced anomalies in heavy-mineral-concentrate samples of W-Sn-Mo-Cu-Pb and Au-Ag-Bi-Cu-Mo in rock samples. Disseminated chalcopyrite in Precambrian igneous rocks may be responsible for some of the Cu anomalies in the Blanca Peak area.

Throughout much of the study area, especially in the vicinity of the range front but not necessarily confined to it, geochemical anomalies, including W-Mo-Sn-Cu-Pb-Zn in heavy-mineral-concentrate samples and Au-Ag-W-Mo-Cu-Pb-Zn-Ba-Bi in rock samples, are probably related to metallization along fractured rock.

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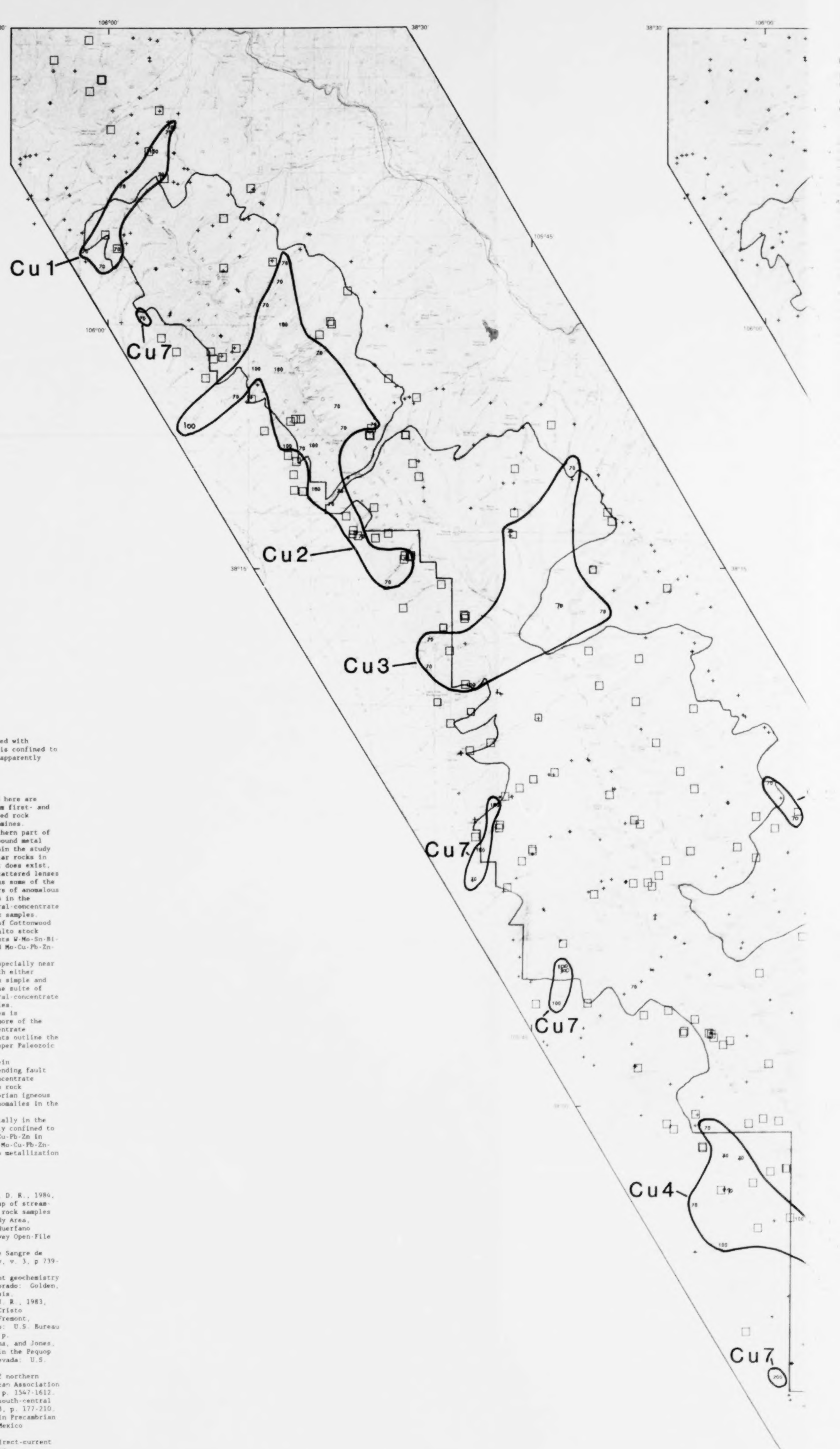


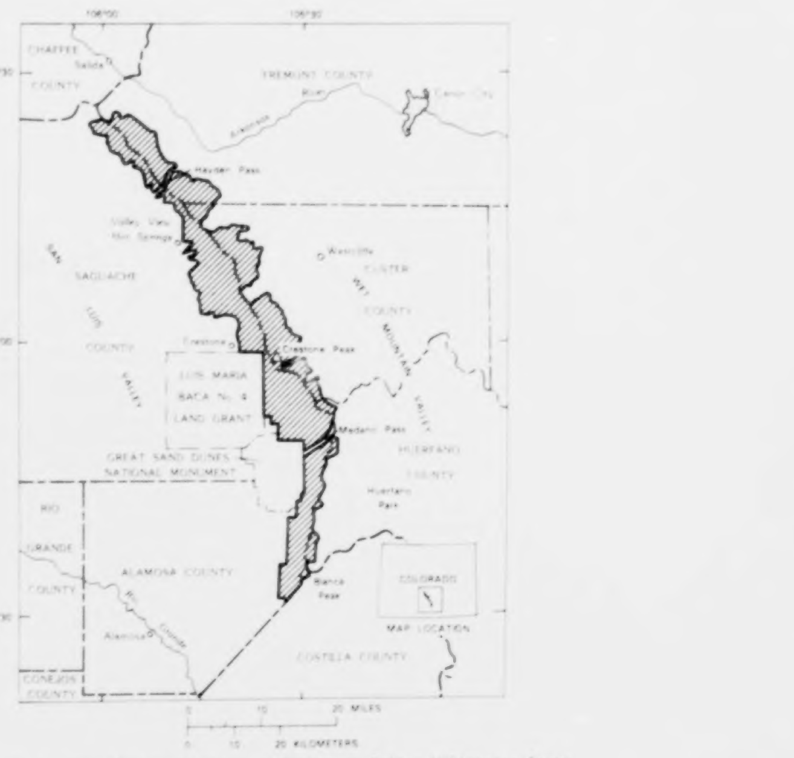
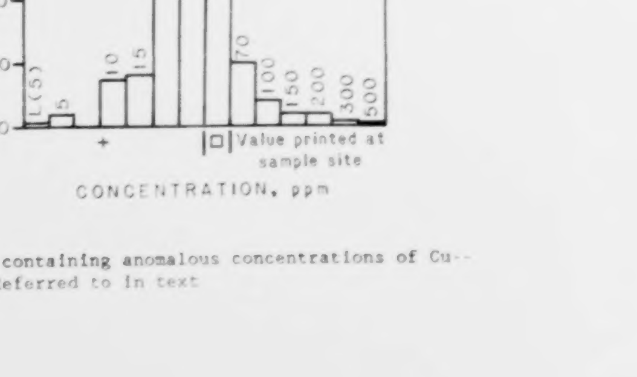


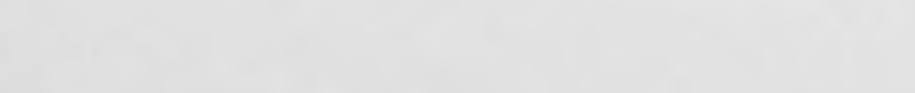
Figure 1.--Map showing location of Sangre de Cristo Wilderness Study Area (diagonally ruled), Colorado.

EXPLANATION FOR FIGURE 2

SYMBOL	PPM-RANGE	NO. IN CLASS	PERCENTILE
□	Less than 50	439	0-57
□	50	228	57-87
Printed value	Greater than or equal to 70	100	87-100
		Total 767	



Area containing anomalous concentrations of Cu. Referred to in text.



MISCELLANEOUS FIELD STUDIES
MAP MF-1635-C
SHEET 1 OF 4

are a few samples in this area which contain more than 100 ppm tin. Most of these samples are close to, but downstream from, northwest-trending faults and may represent metallization along these structures.

In the southern part of the study area three samples contain anomalous tin (area Sn-5). Two of these samples are in the upper part of the Huerfano River and probably represent quartz-vein mineralization near Blanca Peak. One tin anomaly near Chokecherry Gulch is probably related to tin concentration along the range-front fault in this area.

Gold, bismuth, and zinc in heavy-mineral concentrates

Figure 13 shows the distribution of detectable gold, bismuth, and zinc in heavy-mineral-concentrate samples.

Gold was detected at a level of 200 ppm or more in two concentrate samples. The northern sample is located in Precambrian metavolcanic sedimentary rocks in Howard Creek. The source of the gold is not known, although possible stratabound metal occurrences in Precambrian gneiss and quartz-veining or metallization along fractured rock seem most likely. The second sample containing anomalous gold is located in Big Cottonwood Creek. This sample is located in upper Paleozoic sedimentary rocks approximately 3 miles downstream from their contact with the Rito Alto stock. The source for the gold in this sample may be veining or metallization along fractures, and may possibly be related to the Rito Alto stock.

Bismuth occurs in abundances of 20 ppm or more in 18 concentrate samples. All but three of these sample sites are located north of Galena Peak. The samples were all collected from drainages containing Precambrian gneiss, and the bismuth is thought to be related to either the gneiss (as either a background feature or in possible stratabound metal occurrences), quartz-veining, metallization along fractures, or a combination of these sources. The source for the bismuth from the three samples south of Galena Peak is not known but may be veining or metallization along fractures.

Zinc occurs in abundances of 500 ppm or more in eight concentrate samples. Five of these samples are located on the east side of the range north of Hamilton Creek. These samples may be related to possible stratabound metal occurrences in Precambrian rocks in the Red Mountain-Bushnell Peak area. Two samples containing anomalous zinc are located near regional-scale faults and are thought to be related to metallization along these faults. These samples are located in Orient Canyon and South Muddy Creek. A single sample containing anomalous zinc in Goodwin Creek may have as its source U-Cu redbed mineralization which is known to exist about 2 miles upstream from the sample location.

Summary of heavy-mineral-concentrate geochemistry

Figure 14 is a summary map of selected trace-element anomalies in heavy-mineral-concentrate samples. It should be remembered that the map represents anomalous stream drainage samples which originated upstream from the collection sites. Therefore, the source(s) of the anomalies may lie an undetermined distance upstream from the areas outlined.

Area A is anomalous in the elements W-Sn-Mo-Cu-Pb-Zn-Ba-Bi and contains a central "barren" zone which is not anomalous in any of these elements. Several sources may have contributed to the anomalous concentrations in this area. These include suspected Precambrian stratabound metal occurrences, anomalously high background levels of any or all of the elements in a particular rock unit(s), quartz veins, metallization along fractured rock, and replacement of lower Paleozoic sedimentary rocks. Of these sources, only quartz-vein mineralization has been identified to date. However, it is thought that the Precambrian stratabound metal type of deposit has a relatively high likelihood for existence. The existence of a carbonate-replacement deposit seems unlikely.

Area B consists of an approximately semicircular area which is anomalous in two or three of the elements Cu, Pb, and Ba. The source(s) for the anomalies may include one or more of the following types of mineralization: quartz-veining, metallization along fractures, U-Cu redbed occurrences in upper Paleozoic sedimentary rocks, replacement of lower Paleozoic sedimentary rocks, and (or) mineralization associated with the Slide Rock stock. Of these mineral deposit types, quartz-veining and metallization along fractured rock seem to be the deposit types which probably account for the majority of the anomalous sample sites, particularly for the eastern and western parts of area B, along the vicinity of the Alvarado and Sangre de Cristo fault systems, respectively. None of the other mineralization types have been recognized to date in the area, yet the geochemical signature is compatible with any of these sources. The potential for metallization associated with the Slide Rock stock (that is, a porphyry-metal type of system) seems to be relatively low due to the paucity of noticeable alteration associated with the exposed part of the stock. Neither replacement in lower Paleozoic carbonate rocks or U-Cu redbed occurrences in upper Paleozoic sedimentary rocks have been identified in area B. Thus, metallization along fractured rock and quartz-veining seem to be the most likely sources for the anomalies.

Area C contains anomalous W-Mo-Sn-Bi-Pb. This area centers on the Rito Alto stock and the anomalous trace-element patterns are probably related to metallization associated with the stock. This is the only known occurrence of porphyry-type metallization in the study area. The Rito Alto stock was studied by Toulmin (1953) and has been explored via several drill holes. Apparently, the metallization associated with the stock is weakly developed, subeconomic, and (or) of limited extent.

Areas D and E are two small areas which contain anomalous trace-element abundances along major structural features, the Sangre de Cristo and Alvarado fault systems. Area D contains a more complex trace-element signature, consisting of W-Sn-Mo-Bi-Pb-Zn. This signature is apparently related to mineralization in lower Paleozoic carbonate rocks, including the Orient iron mine, and in Precambrian gneiss cut by the Sangre de Cristo fault system. Area E contains anomalous Ba and Pb and is centered on the Rita Alta copper mine.

Area F outlines an area that approximately parallels U-Cu redbed-type occurrences in upper Paleozoic sedimentary rocks. Most of area F contains anomalous amounts of one or more of the elements Cu, Pb, and Ba. These elements are apparently related to the U-Cu mineralization and are thought to be good pathfinder elements for this type of mineralization. Two exceptions to this generalization are parts of Cotton and Spring Creeks on the west side of area F which contain anomalous Sn-Pb-Ba and the northeastern part of area F which contains anomalous amounts of Cu-Pb-Zn-Ba-Bi-Sn. The most likely source for the more complex trace-element anomalies in these areas is quartz-veining or metallization along fractures, especially along the major fault systems which are present in both of these areas. It is also possible that Precambrian stratabound metal occurrences contribute some of the metals in these areas.

Area G contains anomalous abundances of Cu-Pb-Sn, with sporadic occurrences of anomalous amounts of Mo, and (or) Zn. The source(s) of the anomalies in area G is not readily explainable. Three sources seem most likely, including unusually high background values of any or all of these elements, probably in a unit or units of Precambrian gneiss, stratabound metal occurrences in Precambrian gneiss, and (or) metallization along fractured rock.

Area H contains anomalous amounts of Ba and (or) Cu. The source for these anomalies is not known because it is outside the study area boundaries and has not received detailed geologic mapping.

Area I contains anomalous amounts of W-Sn-Mo-Cu-Pb. Anomalies in area I are apparently related to a strongly developed quartz-vein system which trends northwesterly and is well exposed on the north face of Blanca Peak. A semicircular area west of Blanca Peak which contains anomalous amounts of copper could be related to disseminated chalcopyrite identified in Precambrian rocks in this area. Also, a small area near the base of the range including Holbrook Creek and Chokecherry and Chimney Gulches contains anomalous W-Sn-Cu and is probably related to metallization associated with a range-front fault.

ROCK GEOCHEMISTRY

Rock samples were generally collected to represent altered or mineralized rocks at mines or prospects, or "different rocks" such as pegmatites, dikes, or stained rocks, and do not represent a thorough or systematic sampling of the study area. Therefore, the rock data should be used in conjunction with the stream-deposit data, and should not be considered comprehensive on its own.

A summary map of selected elements, including Au, Ag, Pb, Zn, Cu, Mo, Ba, Bi, As, Sb, and W, in rock samples is shown on figure 15. A brief discussion of these elements follows.

Gold in rock samples

Gold was found in abundances of 10 ppm or more in six rock samples. Three of the samples are from quartz-vein samples in Precambrian gneiss in the Pole Creek drainage basin. One of the gold-bearing samples is from a quartz vein exposed on the north face of Blanca Peak, one is from a quartz vein in Carr Gulch, and one is from a quartz vein in Precambrian gneiss near Spanish Creek and the Independence Mine.

Silver in rock samples

Silver occurs in abundances of 5 ppm or more in 17 rock samples. Most of the silver-bearing samples are from quartz veins associated with northwest-trending faults. The veins are hosted by a variety of rock types including Precambrian gneiss and metadiorite and upper Paleozoic sedimentary rocks.

Lead in rock samples

Lead occurs in abundances of 200 ppm or more in 12 rock samples. These samples include a wide variety of rock types including Precambrian-hosted pegmatites, Precambrian granodiorite and amphibolite, quartz veins, and lower Paleozoic carbonate rocks. All samples which contain 200 ppm or more lead are located north of Sand Creek.

Zinc in rock samples

Zinc occurs in abundances of 200 ppm or more in 10 rock samples. Anomalous zinc is found in an assortment of rock types in the study area, but is confined to an area north of Taylor Creek. Rock types which contain anomalous zinc include quartz veins, pegmatites, lower Paleozoic carbonates and quartzites, and tonalite from the Rito Alto stock.

Copper in rock samples

Copper occurs in abundances of 500 ppm or more in 34 rock samples. These samples are scattered throughout the study area and are from a variety of rock types, including U-Cu redbed occurrences, quartz veins, Precambrian amphibolite, skarn, and metadiorite, and various rocks associated with the Rito Alto stock.

Molybdenum in rock samples

Molybdenum occurs in abundances of 5 ppm or more in 26 rock samples. The greatest concentration of rock samples containing anomalous amounts of molybdenum is in the Rito Alto stock area. Rock samples from the stock which contain anomalous molybdenum include tonalite, quartz-monzonite, rhyolite, and quartz veins. Other samples containing anomalous molybdenum occur throughout much of the study area, generally in quartz veins located near regional-scale, northwest-trending fault systems.

Barium in rock samples

Barium occurs in abundances of greater than 5,000 ppm in eight rock samples. Four of these samples are located in the Rito Alto stock, three are peripheral to the stock (one at the Rita Alta mine and two in Hot Springs Canyon), and one is in Hayden Pass Creek drainage. The close association between anomalous barium and the Rito Alto stock suggests a genetic relationship between the two.

Other elements in rock samples

Bismuth, arsenic, antimony, and tungsten are included on the rock geochemistry summary map but are not discussed individually. Generally, these elements occur in detectable quantities in a very limited number of samples in the study area and little is known about their relationship with the different types of mineral deposit types found in the area.

Summary of rock geochemistry

Copper and molybdenum are found in a variety of rock types scattered throughout much of the study area. Barium is generally confined to the vicinity of the Rito Alto stock and is thought to be genetically related to the stock. Lead and zinc are found in anomalous amounts in a variety of rock types, but the anomalies are confined to the northern half of the study area. Silver occurs throughout much of the study area, generally in quartz veins associated with northwest-trending structural elements. Gold is confined to quartz veins hosted by Precambrian gneiss and apparently localized by northwest-trending structures.

SUMMARY

The geochemical interpretations presented here are based on stream drainage samples collected from first- and second-order drainages supplemented by scattered rock samples collected mostly at prospect pits and mines.

The area around Bushnell Peak in the northern part of the study area may contain Precambrian stratabound metal occurrences. Although not yet recognized within the study area, this type of deposit does occur in similar rocks in nearby areas. If this type of mineral deposit does exist, it probably occurs as small, discontinuous, scattered lenses and (or) pods. The Bushnell Peak area contains some of the highest values and some of the largest clusters of anomalous samples in the study area, including anomalies in the elements W-Sn-Mo-Cu-Pb-Zn-Ba-Bi in heavy-mineral-concentrate samples and Ag-Pb-Zn-Cu-As-Sb-Bi-Ba-Mo in rock samples.

South of Bushnell Peak, in the vicinity of Cottonwood Peak, metallization associated with the Rito Alto stock produced trace-element anomalies in the elements W-Mo-Sn-Bi-Pb-Ba in heavy-mineral-concentrate samples and Mo-Cu-Pb-Zn-Ba-Bi in rock samples.

Between Cottonwood and Bushnell Peaks, especially near the range fronts, metallization associated with either quartz-veining or fractured rock produced both simple and complex trace-element anomaly signatures in the suite of elements Cu-Pb-Zn-Ba-W-Sn-Mo-Bi in heavy-mineral-concentrate samples and Au-Ag-Ba-Bi-Cu-Pb-Zn in rock samples.

Much of the central part of the study area is characterized by anomalous amounts of one or more of the elements Cu, Pb, and Ba in heavy-mineral-concentrate samples. Anomalous abundances of these elements outline the occurrence of U-Cu redbed mineralization in upper Paleozoic sedimentary rocks.

In the vicinity of Blanca Peak, quartz-vein mineralization associated with a northwest-trending fault system produced anomalies in heavy-mineral-concentrate samples of W-Sn-Mo-Cu-Pb and Au-Ag-Bi-Cu-Mo in rock samples. Disseminated chalcopyrite in Precambrian igneous rocks may be responsible for some of the Cu anomalies in the Blanca Peak area.

Throughout much of the study area, especially in the vicinity of the range front but not necessarily confined to it, geochemical anomalies, including W-Mo-Sn-Cu-Pb-Zn in heavy-mineral-concentrate samples and Au-Ag-W-Mo-Cu-Pb-Zn-Ba-Bi in rock samples, are probably related to metallization along fractured rock.

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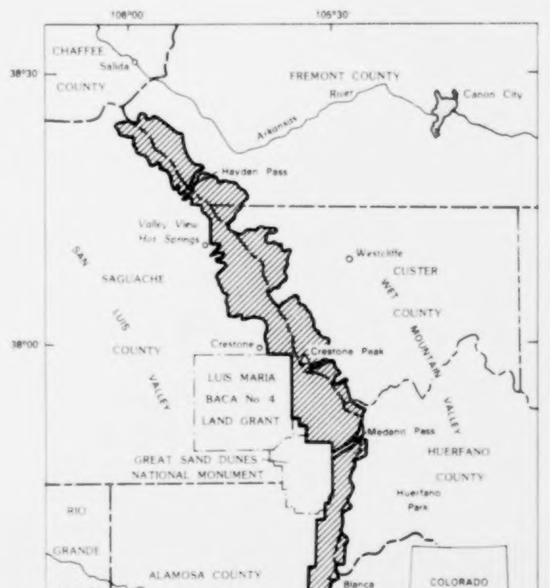
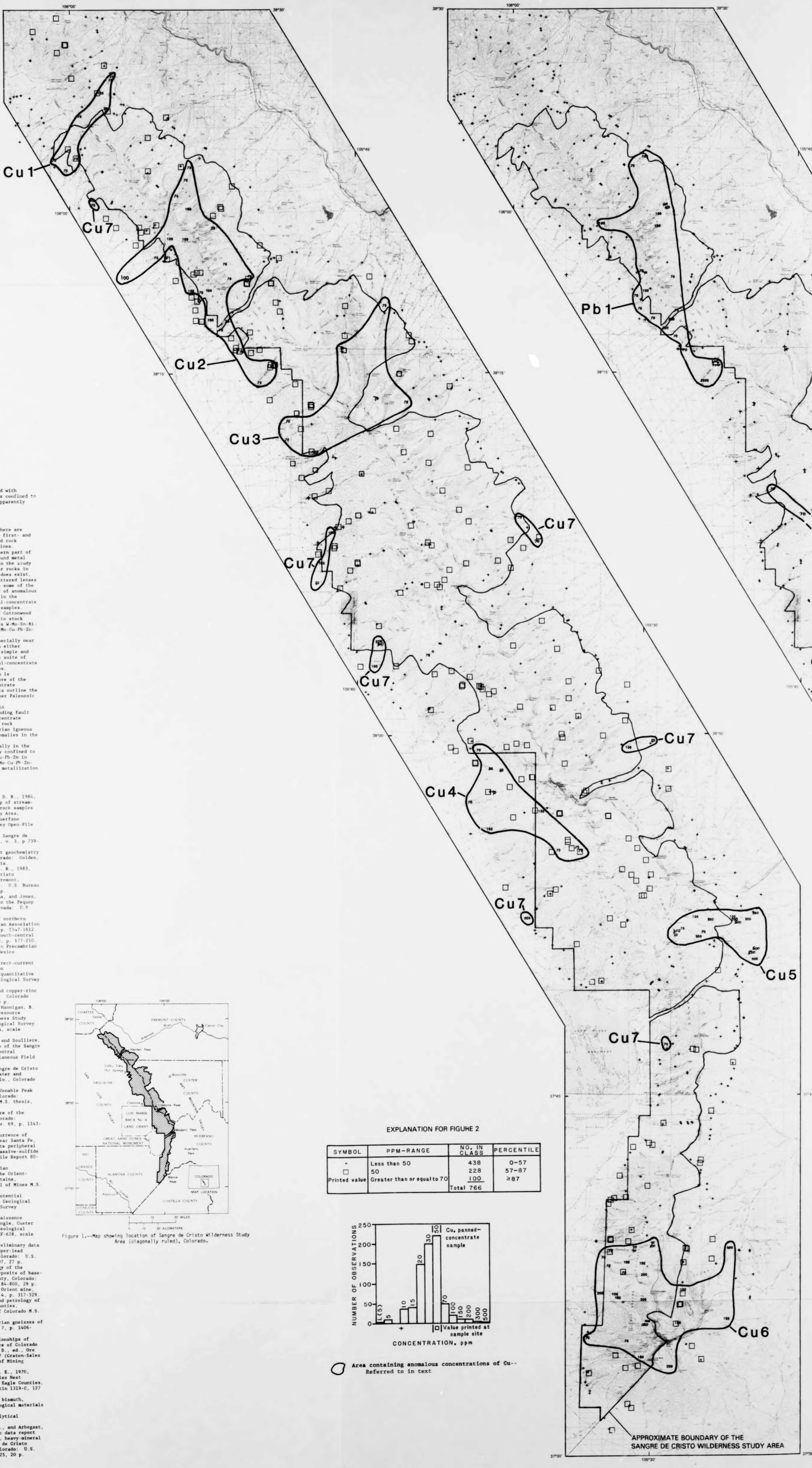


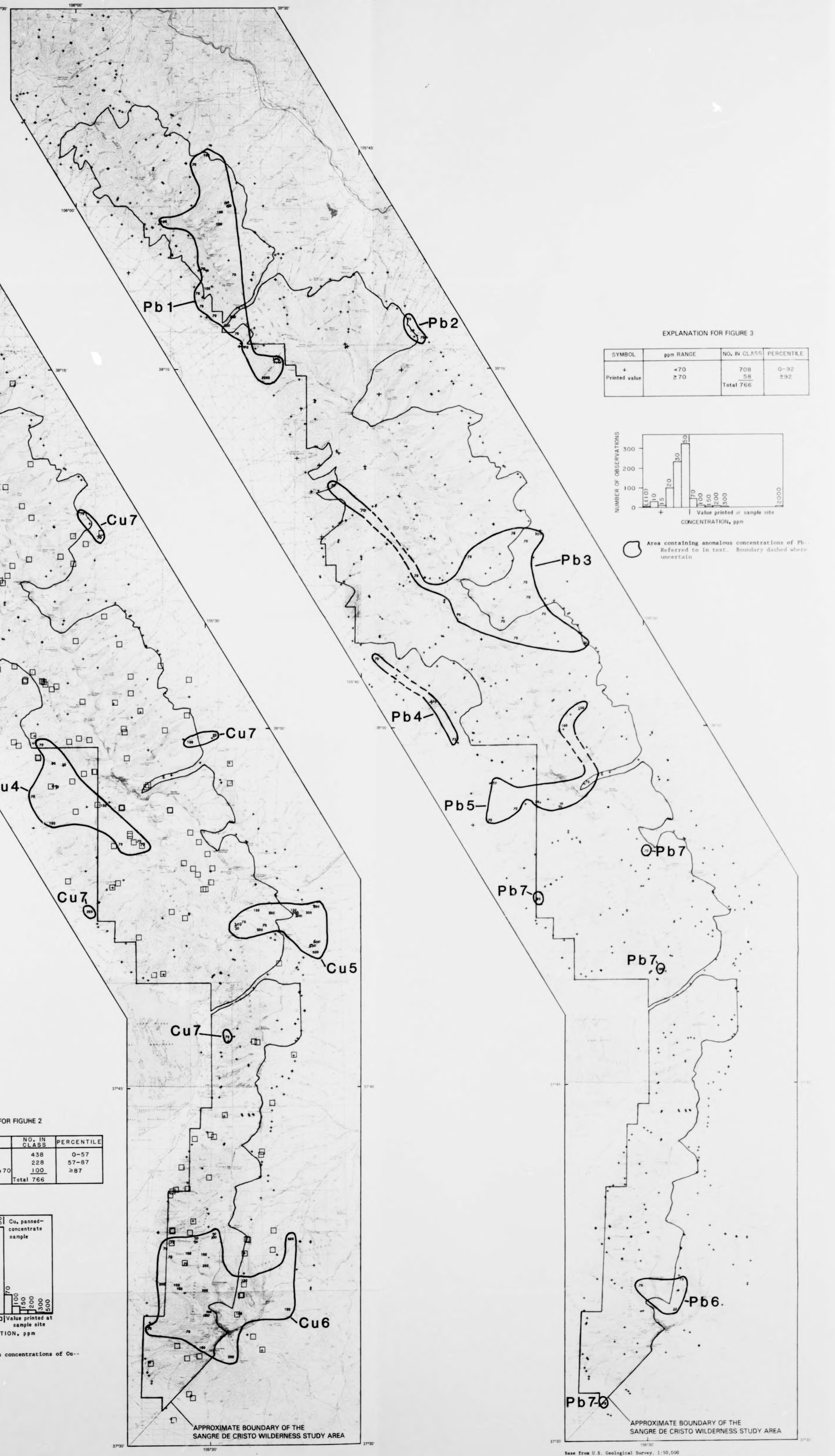
Figure 1.--Map showing location of Sangre de Cristo Wilderness Study Area (diagonally ruled), Colorado.


38°30'
106°00'
105°45'
38°15'
38°00'
37°45'
37°30'
105°30'
Cu1
Cu2
Cu3
Cu4
Cu5
Cu6
Cu7
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA
NUMBER OF OBSERVATIONS
0
50
100
150
200
250
L(5)
5
10
15
20
30
50
70
100
150
200
300
500
Cu, panned-concentrate sample
+
Value printed at sample site
CONCENTRATION, ppm
Area containing anomalous concentrations of Cu-- Referred to in text

EXPLANATION FOR FIGURE 2

SYMBOL	PPM-RANGE	NO. IN CLASS	PERCENTILE
+	Less than 50	438	0-57
□	50	228	57-87
Printed value	Greater than or equal to 70	100	≥87
		Total 766	

FIGURE 2.-Cu IN STREAM-SEDIMENT SAMPLES


38°30'
106°00'
105°45'
38°15'
38°00'
37°45'
37°30'
105°30'
Pb1
Pb2
Pb3
Pb4
Pb5
Pb6
Pb7
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA
NUMBER OF OBSERVATIONS
0
100
200
300
L(10)
10
15
20
30
50
70
100
150
200
300
2000
+
Value printed at sample site
CONCENTRATION, ppm
Area containing anomalous concentrations of Pb-- Referred to in text. Boundary dashed where uncertain

EXPLANATION FOR FIGURE 3

SYMBOL	ppm RANGE	NO. IN CLASS	PERCENTILE
+	<70	708	0-92
Printed value	≥70	58	≥92
		Total 766	

Base from U.S. Geological Survey, 1:50,000
Saguache, Custer, Alamosa, Huerfano, and Costilla Counties

FIGURE 3.-Pb IN STREAM-SEDIMENT SAMPLES

The geochemical investigation consisted of a pilot study, used to determine the most effective sample media for the definition of the known mineral deposit types in the study area, followed by a regional-scale stream drainage sampling program and a rock sampling program at selected mines and prospects. The total number of samples which were collected include 710 heavy-mineral-concentrate samples, 767 minus-80 mesh stream-sediment samples, and 145 rock samples. All samples were analyzed for 31 elements by semiquantitative emission-spectrographic methods, and some rock and stream-sediment samples were also analyzed for selected elements by wet chemical methods.

GEOLOGY

The two most common rock types in the study area are Precambrian crystalline and upper Paleozoic clastic sedimentary rocks. Other rock types which occur in less voluminous amounts include lower Paleozoic sedimentary rocks, including carbonates; Jurassic sedimentary rocks; and Tertiary plutonic, volcanic, and sedimentary rocks. Two structural styles are common in the study area. These include a period of compressional tectonics during Laramide time, which produced a series of thrust sheets, and a younger (Oligocene to Recent) period of extensional tectonics, which produced the presently exposed horst-and-graben configuration of the Sangre de Cristo Mountains and the San Luis and Wet Mountain valleys.

Recent mapping by members of the U.S. Geological Survey resulted in a regional-scale (1:62,500) map (Johnson and others, 1984b) from which much of the geologic information presented below was taken. Other geologic studies from within the study area include structural and stratigraphic studies of the northern part of the Sangre de Cristo range by Gableman (1952) and Litsey (1958) and a petrographic and petrologic study of the Rito Alto stock by Toulmin (1953).

PRECAMBRIAN ROCKS

Precambrian metamorphic rocks are divided into two groups on the geologic map, corresponding to rocks whose original volcanic texture is still identifiable (Xvs) and gneisses whose original texture is not identifiable (Xgn). The metavolcanic rocks are confined to the northern part of the study area whereas the gneisses occur in the northern, west-central, and southern parts of the study area.

There are three apparent ages of Precambrian intrusive rocks in the study area (R. B. Taylor, personal communication). The oldest intrusive rocks are of the same approximate age as the gneiss protolith and occur in the northern part of the area as granodiorite and diorite, and in the upper part of Sand Creek as granodiorite. Precambrian intrusive rocks of the 1.7-b.y.-age group include tonalite and metadiorite in the southern part of the study area and a granodiorite mass exposed along Rito Alto Creek in the central part of the study area. A body of quartz monzonite east of Crestone is the youngest Precambrian intrusive rock in the study area, apparently belonging to the 1.45-b.y.-age group.

PALEOZOIC SEDIMENTARY ROCKS

Lower Paleozoic sedimentary rocks, totaling less than 400 feet in thickness, occur in scattered places in the northern part of the study area (Gableman, 1952). These rocks include the Lower Ordovician Manitou Limestone, Middle Ordovician Harding Sandstone, and Upper Ordovician Fremont Dolomite; the Mississippian(?) to Upper Devonian Chaffee Group; and the Lower Mississippian Leadville Limestone.

Much of the central and eastern parts of the study area are composed of upper Paleozoic units, including the Permian and Pennsylvanian Sangre de Cristo, Middle Pennsylvanian Minturn, and Middle and Lower Pennsylvanian Belden Formations. These rocks are composed principally of arkose, sandstone, or shale and total some 12,000 feet in thickness (Johnson and others, 1984a). Parts of the Sangre de Cristo Formation include clasts of fennitized rock and nephelinite believed to be derived from a large, concealed Cambrian(?) alkaline intrusive complex located somewhere west or southwest of the study area (R. B. Taylor, personal communication).

Younger sedimentary rocks do not comprise a significant proportion of the study area, but can be found along the boundaries and outside the area.

TERTIARY IGNEOUS ROCKS

Tertiary plutonic rocks comprise two small stocks of Tertiary age, the Rito Alto and Slide Rock Mountain stocks, which occur in the north-central part of the area. Both stocks are near-surface features, and several andesitic to rhyolitic dikes in the area are apparently related to these or similar unexposed stocks (Toulmin, 1953).

STRUCTURAL SETTING

The major structural features of the study area are Laramide thrusts and late Oligocene to Holocene normal faults (Karig, 1963; Koch, 1963; Litsey, 1958; Nolting, 1970; Scott and Taylor, 1974). The Laramide faulting produced a series of northwest-trending structures with mostly west-dipping surfaces.

Extensional tectonics in Oligocene time produced the present day Sangre de Cristo Mountains and the San Luis and Wet Mountain valleys. The Sangre de Cristo Mountains in the study area are bounded by two large normal faults, the Sangre de Cristo fault along much of the west side of the range and the Alvarado fault along the northern part of the east side of the range, related to this period of extensional tectonics. Faulting is still active in the San Luis valley (Scott, 1970) but may have ceased in the Wet Mountain valley.

METALLIC MINERAL DEPOSITS

WITHIN THE STUDY AREA

Few reports have been published regarding metallic mineral deposits within the study area. Bagg (1908) described copper deposits in sandstone near Rito Alto Peak, Gableman (1953) defined a mineral belt in south-central Colorado, including brief descriptions of several small deposits in the study area, and Toulmin (1953) described molybdenum mineralization associated with the Rito Alto stock.

Metallic mineral deposits which have been studied in recent years within the study area include uranium and copper from redbed-type occurrences, molybdenum from the Rito Alto stock, and copper and gold from vein deposits. There are no mines with significant mineral production within the study area (Johnson and others, 1984a).

OUTSIDE THE STUDY AREA

Metallic mineral deposits which occur adjacent to or within a few miles of the study area include iron from replacement of lower Paleozoic sedimentary rocks at the Orient mine (Stone, 1934; Nolting, 1970), Precambrian stratabound Cu-Pb-Zn-Au-Ag deposits such as those that occur near Sedalia, Colorado, tungsten-bearing veins such as those at Cleora, Colorado, and base- and precious-metal vein systems related to Tertiary igneous activity such as at Silvercliffe, Colorado. Other deposit types which occur in nearby areas in rocks similar to those found in the study area include porphyry-metal deposits and Pb-Zn-Ag replacement deposits of lower Paleozoic sedimentary rocks.

GEOCHEMISTRY

Samples collected for trace-element analysis involved two studies, a pilot study and a regional-scale study. In the pilot study, conducted during May and June 1982, 20 samples were collected for each of three different media: minus-80 mesh (0.180 mm) stream sediments, heavy-mineral-concentrates, and rocks. The sampling, preparation, analytical methods, and data for the pilot study samples are discussed in Zimbelman and others (1983). After selection of optimum sample media in the pilot study a regional-scale trace-element geochemical survey was performed during July 1982.

Composite stream-sediment samples were collected within or adjacent to the study area at first- and second-order drainages as shown on 1:24,000-scale topographic maps. Approximately 2 kg of sediment was collected, air-dried, and then sieved through a 180-micron sieve. The coarse fraction was then discarded and the fines saved for analysis.

Each sample was analyzed for 31 elements using a semiquantitative six-step, direct-current arc, optical-emission spectrographic method (Grimes and Marranzino, 1968). Additional wet-chemical analyses were used to determine As, Sb, Bi, Cd, and Zn at lower levels than possible by the spectrographic method. These samples were analyzed by using a modification of the atomic absorption spectrometry technique described by Viets (1978).

Heavy-mineral-concentrate samples were collected within or adjacent to the study area at sites that are usually also the location of stream-sediment samples. The heavy-mineral-concentrate samples were panned in the field, whenever possible, then air-dried. At the laboratory, the highly magnetic material was removed by a magnet and any light-weight material was removed by allowing the heavier fraction to settle through bromoform (specific gravity 2.82). The heavy-mineral fraction was then separated into a magnetic and a nonmagnetic fraction using a Frantz Isodynamic Separator at a setting of 0.6 ampere, with 15° forward and 15° side settings. The nonmagnetic fraction was pulverized in an agate mortar before analysis. The heavy-mineral-concentrate samples were analyzed for 31 elements by the same spectrographic methods described above.

Rock samples were collected from within or adjacent to the study area to represent either mineralized rock or unusual rock types not characteristic of the most voluminous rock in any particular area such as dikes, veins, or visibly stained rocks. Rock samples were taken from unweathered outcrops wherever possible, ground to minus-200 mesh with a vertical pulverizer, and analyzed for 31 elements using the six-step semiquantitative spectrographic method described above.

The data and the sampling, preparation, and analytical methods for each of these media are discussed in Adrian and others (1984).

DETERMINATION OF THRESHOLD AND ANOMALOUS LEVELS

Throughout this report the term anomalous is used to refer to samples which contain a greater abundance of an element than its threshold value. The threshold value for each element was defined after visual inspection of the frequency distributions (which are included with the element distributions shown on figures 2-13). The geochemical discussion presented below interprets many of the trace-element anomalies in terms of two metallic mineral deposit

Found throughout the study area are geochemical anomalies apparently related to iron- and (or) manganese-stained, fractured rock. The zones of fractured rock contain significant geochemical anomalies that are hard to explain geologically. Tweto and others (1970) attribute similar features in the Gore Range, Colorado, to "metal-bearing solutions that diffused into fault systems in small quantities from great depth." Furthermore, these workers found no geologic (including intrusive bodies and altered rock) or magnetic evidence for a local source of the metal-bearing solutions. The geochemical anomalies in rock and stream-sediment samples from the Gore Range, Colorado, included the elements copper, lead, zinc, gold, silver, molybdenum, bismuth, arsenic, antimony, cadmium, mercury, and tin (Tweto and others, 1970). Another example of anomalous trace-element abundances in fractured rock, with no other apparent mineralizing features present, is a study of the Pequop Mountains, Nevada (Erickson and others, 1966). These workers found anomalously high values of zinc, lead, mercury, and silver in oxidized iron-rich fracture filling and small gossan pods.

ARRANGEMENT OF THE GEOCHEMICAL DISCUSSIONS

Throughout this report, the discussions of the trace-element distributions are arranged such that an introductory paragraph explains all of the interpreted geologic sources and their locations for any particular element followed by a more detailed definition and discussion of clusters of anomalous samples for each particular element. The clusters of anomalous samples are outlined in figures 2 through 6 for stream-sediment samples and in figures 7 through 12 for heavy-mineral-concentrate samples.

STREAM-SEDIMENT GEOCHEMISTRY

In general, the trace-element stream-sediment data are best interpreted in terms of background lithogeochemistry most applicable to petrogenetic, structural, or geologic provenance studies rather than mineralizing processes. For example, from a population of 767 samples, the number of samples which occur at levels greater than the spectrographic detection limits for selected elements include: Ag-6; As-0; Au-0; Bi-1; Cd-0; Mo-20; Sb-0; Sn-4; and W-1. Therefore, additional data for As, Zn, Cd, Bi, and Sb were obtained by atomic absorption techniques for the stream-sediment samples.

Copper in stream-sediment samples

Anomalous copper is interpreted to be related to a variety of sources in the study area. These include possible stratabound sulfide mineralization in Precambrian gneiss in the northern part of the area; quartz-veining and (or) seepage along fractured-rock mineralization throughout much of the area; replacement of lower Paleozoic sedimentary rocks in the northern part of the area; the Rito Alto stock in the Cottonwood Peak vicinity; and U-Cu redbed mineralization throughout much of the central part of the area.

Figure 2 shows the distribution of copper in stream-sediment samples. Samples which contain 70 ppm or more copper are referred to as anomalous. This corresponds to 100 samples or the approximate upper 13 percent of the stream-sediment population.

Anomalous copper in area Cu-1 is apparently related to either possible stratabound metal occurrences in Precambrian gneiss, metallization along fractured rock, veining along the Sangre de Cristo fault system, or a combination of these sources.

Anomalous copper in area Cu-2 may be related to a variety of sources. These include replacement of lower Paleozoic sedimentary rocks, especially carbonates, veining and (or) metallization along fractured rock, stratabound metal occurrences in Precambrian gneiss, or any combination of these sources.

Anomalous copper in area Cu-3 is apparently related to the Rito Alto stock and its associated metallization.

Anomalous copper in area Cu-4 is not readily explainable. It is probably related to either high background values in Precambrian gneiss or U-Cu redbed occurrences, or both.

Anomalous copper in area Cu-5 may be due to metallization along fractured rock or to anomalous copper in the Sangre de Cristo Formation. The area does not contain anomalous concentrations of other elements commonly associated with fracture-controlled anomalous areas, and therefore the second explanation is favored.

Anomalous copper in area Cu-6 probably is related to veining and (or) metallization along fractured rock in the Blanca Peak vicinity.

Anomalous copper in areas Cu-7 are related either to metallization along fractured rock, U-Cu redbed occurrences, or a combination of these sources.

Lead in stream-sediment samples

Anomalous lead is interpreted to be related to a variety of sources including: quartz-veining in, and possibly replacement of, lower Paleozoic carbonate rocks and (or) stratabound sulfide occurrences in Precambrian rocks in the Bushnell Peak area; U-Cu redbed occurrences in the central part of the area; quartz-vein mineralizaiton in the Blanca Peak area; and fracture-controlled seepage and (or) quartz-veining along parts of the Sangre de Cristo fault system.

Figure 3 shows the distribution of lead in stream-sediment samples. Samples which contain 70 ppm or more lead are considered anomalous. This corresponds to 58 samples or the approximate upper 8 percent of the stream-sediment population.

Anomalous lead in area Pb-1 closely parallels the outcrop of lower Paleozoic sedimentary rocks. This correlation and the known occurrence of galena-bearing veins in the vicinity of Galena Peak suggests that much of the lead is from veins in the lower Paleozoic units. Two other sources may have contributed to the lead anomaly distribution pattern in this area. These are replacement deposits in lower Paleozoic sedimentary rocks (especially carbonates) and (or) stratabound metal occurrences in Precambrian gneiss. Neither type of mineralization has been identified in this part of the study area to date, although both occur in nearby areas in rocks very similar to those found in the study area.

Anomalous lead in area Pb-2 is apparently related to quartz-veining and (or) metallization along fractured rock.

Anomalous lead in area Pb-3 closely parallels the northern two-thirds of the known outcrop of U-Cu redbed occurrences. Although this area contains many anomalous samples, none of the samples exceed 100 ppm lead.

Area Pb-4 contains three samples which are anomalous in lead. All three samples are located within close proximity to the Sangre de Cristo fault system and are probably related to either quartz-veining or metallization along fractured rock localized by this system.

Anomalous lead in area Pb-5 is probably related to either U-Cu redbed occurrences, metallization along fractured rock, or a combination of these sources.

Anomalous lead in area Pb-6 is probably related to quartz-vein mineralization in the Blanca Peak area.

Four samples (areas Pb-7) are not part of any large cluster of samples which contain anomalous lead. These samples are downstream from areas of faulting and may represent either metallization along faults or fractures or quartz-veining associated with the structures.

Zinc in stream-sediment samples

Anomalous zinc is apparently related to a variety of sources in the study area including: possible Precambrian-hosted stratabound sulfide occurrences in the northern part of the area; U-Cu redbed occurrences in the central part of the area; quartz-veining and (or) seepage along fractured rock in the southern part of the area; and unknown, probably background related occurrences in the south-central part of the area. Replacement of lower Paleozoic sedimentary rocks in the northern part of the study area and vein and (or) seepage mineralization throughout much of the study area may also be responsible for some of the zinc anomalies.

Figure 4 shows the distribution of zinc in stream-sediment samples. Samples which contain 100 ppm or more zinc are referred to as anomalous. This corresponds to 96 samples or the approximate upper 13 percent of the population.

Anomalous zinc in area Zn-1 closely overlaps both an area of Precambrian gneiss that is believed favorable for stratabound metal occurrences (R. B. Taylor, personal communication) and lower Paleozoic sedimentary rocks, including carbonates. The anomalous zinc could be related to either the stratabound metal occurrences, quartz-veining and (or) metallization along fractures in either rock type, or possible replacement deposits in the lower Paleozoic rocks.

Anomalous zinc in areas Zn-2 and Zn-3 closely correlates with the northern and southern parts, respectively, of U-Cu redbed occurrences. The zinc anomalies are apparently related to this type of mineral deposit.

Anomalous zinc in area Zn-4 is not readily explainable. Because of the paucity of anomalies of other hydrothermal-related elements in this area, the source is believed to be lithologically controlled and not related to any metallizing processes.

Anomalous zinc in area Zn-5 is related to quartz-veining and (or) metallization along fractures in the vicinity of Blanca Peak.

Scattered zinc anomalies not related to any of the above-mentioned patterns occur in several areas which contain known faults (areas Zn-6). These anomalies are probably related to nearby faults, representing either metallization along the faults or quartz-veining controlled by the structures.

Cadmium in stream-sediment samples

Anomalous cadmium is related to U-Cu redbed mineralization in the central part of the study area, the Rito Alto stock in the Cottonwood Peak vicinity, possible stratabound sulfide occurrences in Precambrian gneiss in the northern part of the area, and quartz-veining and (or) seepage along fractured rock mineralization throughout much of the area.

Figure 5 shows the distribution of cadmium in stream-sediment samples. Samples which contain 0.4 ppm or more cadmium are referred to as anomalous. This includes 105 samples or the approximate upper 14 percent of the stream-sediment population.

Anomalous cadmium in area Cd-1 is probably related to either stratabound metal occurrences in Precambrian gneiss, metallization along fractured rock, or a combination of these sources.

The northern part of the study area contains anomalous amounts of Cu, Pb, Zn, and Cd in stream-sediment samples. These metals are probably related to a number of processes, including quartz-veining, seepage along fractured rock, replacement of lower Paleozoic rocks, and possible stratabound metal deposits in Precambrian rocks.

Stream-sediment samples draining the Rito Alto stock, near Cottonwood Peak, are anomalous in Cu and Cd.

Much of the central part of the study area contains stream-sediment samples anomalous in one or more of the elements Cu, Pb, Zn, As, and Cd. These metals are related to U-Cu redbed occurrences in this part of the study area.

Throughout much of the study area, and including the Sangre de Cristo fault system, the Alvarado fault system, and a northwest-trending fault system near Blanca Peak, quartz-vein mineralization and seepage along fractured rock has produced anomalous abundances of Cu, Pb, Zn, As, and Cd in stream-sediment samples.

An area south of Medano Pass contains anomalous amounts of Zn in stream-sediment samples. These anomalies may be due to a high background level of Zn in Precambrian gneiss, veining or seepage along fractured rock, or, possibly, stratabound metal occurrences in the gneiss.

HEAVY-MINERAL-CONCENTRATE SAMPLES

Heavy-mineral-concentrate samples are subsamples of stream sediments. The heavy-mineral-concentrate samples were collected at most of the same sites as the stream-sediment samples, panned in the field whenever possible with a standard gold pan, and separated into a nonmagnetic heavy-mineral fraction in the laboratory (Adrian and others, 1984). This process selectively concentrates many ore-related elements in the heavy-mineral-concentrate samples and reduces the influence of many background minerals which can dilute or mask ore-related mineral abundances.

Copper in heavy-mineral concentrates

A number of sources are responsible for producing anomalous copper values throughout the study area. The exact proportion any particular source is contributing in any part of the area is not known with a great degree of certainty. However, it is felt that in the northernmost part of the area the copper anomalies are most likely related to scattered, unidentifiable sulfide deposits in Precambrian gneiss. Near Galena Peak and in the lower Paleozoic carbonate rocks in general, copper values are related to replacement deposits and (or) veining. Near Cottonwood Peak, scattered copper anomalies are related to porphyry-type mineralization associated with the Rito Alto stock. South of Cottonwood Peak, near the crest of the range, many copper anomalies are related to U-Cu redbed mineralization in upper Paleozoic clastic sedimentary rocks. In the southern part of the area copper anomalies are related to a strongly developed vein system associated with a northwest-trending fault system in the vicinity of Blanca Peak. Throughout much of the range, especially near the foot of the range, scattered copper anomalies are related to quartz-veining and (or) seepage along fractured rock.

Figure 7 shows the distribution of copper in heavy-mineral-concentrate samples. Samples containing 100 ppm or more copper are considered to be anomalous. This corresponds to 83 samples representing the upper 11 percent of the concentrate population.

Seven samples in the northern part of the study area (area Cu-8) contain anomalous copper which is most easily interpreted as originating from either stratabound metal occurrences in Precambrian gneiss, metallization along fractures, or a combination of these sources.

Thirty-five samples contain anomalous copper in an irregularly shaped area which closely mimics the outcrop of lower Paleozoic sedimentary rocks between West Creek and Steel Canyon (area Cu-9). This area contains one of the highest densities of samples containing anomalous copper in the study area. The anomalies are probably related to one of two sources: (1) replacement deposits in carbonate-bearing lower Paleozoic rocks, or (2) veins or fracture-controlled metallization in a variety of rock types in the area.

A few scattered occurrences of anomalous copper center around the Rito Alto stock (area Cu-10). These anomalies are probably related to the stock and its associated metallization.

Scattered occurrences of anomalous copper occur from the upper part of Cotton Creek south to South Colony and Cottonwood Creeks (area Cu-11). These occurrences are probably related to scattered U-Cu redbed lenses which occur in the uppermost part of the Minturn Formation and the lowermost part of the Sangre de Cristo Formation. These anomalous samples are generally within 2-3 miles downstream of the outcrop of the Minturn and Sangre de Cristo contact and are considered to be a good pathfinder for U-Cu redbed mineralization.

Six anomalous copper values in the lower parts of Pole, Sand, Cottonwood, South Crestone, and Cold Creeks (area Cu-12) are apparently related to metallization along fractured rock and (or) vein mineralization along a northwest-trending fault system in Precambrian gneiss.

Five samples contain anomalous copper in the upper parts of Cottonwood, North Muddy, Medano, and Bruff Creeks (area Cu-13). Possible sources include U-Cu redbed occurrences in upper Paleozoic sedimentary rocks and either veining or metallization along fractured rock. Neither type of mineralization has been identified in the area.

Anomalous copper values in the Blanca Peak area (area Cu-14) center on the fault-controlled vein system near Blanca Peak. Two samples from the South Fork of the Huerfano River also contain anomalous copper. The source for these copper anomalies is probably the extensive vein system associated with the northwest-trending fault system in the vicinity of Blanca Peak. However, contribution from scattered occurrences of disseminated chalcopyrite in Precambrian metadiorite is also possible.

Lead in heavy-mineral concentrates

Numerous sources appear likely to have produced lead anomalies in the heavy-mineral-concentrate samples. These include possible Precambrian stratabound sulfide deposits in the northern part of the study area, veins and (or) possible replacement deposits in lower Paleozoic sedimentary rocks in the north-central part of the area, redbed associated occurrences throughout much of the central part of the area, metallization associated with the Rito Alto Stock in the Cottonwood Peak vicinity, and scattered vein and (or) fracture-related seepage deposits, including those in the Blanca Peak area, throughout much of the length of the Sangre de Cristo fault system, and parts of the Alvarado fault system.

Figure 8 shows the distribution of lead in heavy-mineral-concentrate samples. Samples which contain 200 ppm or more lead are referred to as anomalous. This corresponds to 84 samples representing the upper 12 percent of the population.

In general, the distribution of samples containing anomalous lead is less clustered than many of the other elements discussed in this report. Lead anomalies occur in several small clusters throughout a larger portion of the study area.

Area Pb-8 includes an approximately circular area containing many samples anomalous in lead. This area closely outlines a sillimanite gneiss complex (R. B. Taylor, personal communication) which may contain Precambrian stratabound metal deposits. The lead anomalies in this area may be related to either the postulated stratabound metal bodies, high local background lead values in a unit or units of Precambrian gneiss, concentration of metals along fractures, or any combination of these sources.

Area Pb-9 contains anomalous lead which is probably related to either Precambrian stratabound sulfide deposits in the uppermost parts of the drainages, vein and (or) replacement deposits in lower Paleozoic sedimentary rocks, or a combination of these occurrence types.

Area Pb-10 contains one of the most densely clustered areas of anomalous lead in the study area along with some of the highest lead values (greater than 20,000 ppm). The lead in area Pb-10 is probably derived from metallization along fractures and (or) vein type mineralization associated with the Sangre de Cristo fault system.

Area Pb-11 contains four samples with anomalous lead values. The lead in this area is apparently related to metallization associated with the Rito Alto stock.

Anomalous lead in area Pb-12 is apparently related to metallization along fractures and (or) vein type mineralization associated with the Sangre de Cristo fault system.

Lead anomalies in areas Pb-13 are apparently related to U-Cu redbed mineralization in upper Paleozoic sedimentary rocks. This source could also be complemented with lead derived from metallization along various faults upstream from any of the anomalous samples.

Area Pb-14 contains many lead anomalies confined to the lowermost parts of their respective drainages. Two sources seem possible for the lead, U-Cu redbed deposits and (or) metallization along fractures. The latter source is favored for having provided most of the lead because of the lack of lead in drainages immediately below known redbed occurrences and the proximity of the Alvarado fault system to the anomalies.

Scattered lead anomalies in areas Pb-15 are probably related to metallization along fractures and (or) vein mineralization associated with the Sangre de Cristo fault system.

Anomalous lead in area Pb-16 is related to Tertiary veining and (or) seepage along fractures in the Blanca Peak area.

Lead anomalies in scattered, relatively isolated occurrences (areas Pb-17) are probably related to veining or metallization along fractured rock located near the edges of the mountain range and associated with the range front fault systems.

Barium in heavy-mineral concentrates

Most of the samples containing anomalous amounts of barium occur north of latitude 38°. Three sources appear most likely for explaining the anomalous barium: possible Precambrian-hosted stratabound sulfide occurrences in the northern part of the study area; U-Cu redbed occurrences in [illegible]

Figure 9 shows the distribution of barium in heavy-mineral-concentrate samples. Samples which contain 5,000 ppm or more barium are referred to as anomalous. This

are near the Alvarado fault zone and are probably related to veining along this zone.

Only a few scattered occurrences of anomalous barium occur south of latitude 38°. These include single point anomalies in Cottonwood, South Muddy, Aspen, and Bruff Creeks. All of these occurrences are near major faults, and contain barium in the lowest 50th percentile upstream from the faults. Therefore, it is reasonable to assume that the barium is coming from metallization along these faults.

Three samples in the upper part of the South Fork of the Huerfano River contain anomalous amounts of barium (area Ba-6). The source of these anomalies is not known as the geologic mapping did not include this area in its study.

Molybdenum in heavy-mineral concentrates

Clusters of samples containing anomalous amounts of molybdenum occur in five areas. The northernmost area contains the highest concentrations of anomalous samples and is probably related to either high background molybdenum values in Precambrian gneiss, anomalous concentrations of molybdenum in Precambrian stratabound sulfide occurrences, seepage along fractured rock, or a combination of these processes. Anomalous molybdenum in the Rito Alto stock area is apparently related to the stock and its associated metallization. Anomalous molybdenum in the central part of the area is not readily explainable. Potential sources in this area include high background levels in Precambrian gneiss or the Sangre de Cristo Formation, concentrations in Precambrian stratabound sulfide occurrences, U-Cu redbed occurrences, fracture-related seepage, or a combination of these processes. Anomalous concentrations of molybdenum in the southern part of the study area are apparently related to veining and (or) seepage along fractured rock. The fault systems which are apparently responsible for localizing the veins and (or) seepages include the northwest-trending fault system in the Blanca Peak area and the range fault system in the southernmost part of the area.

Figure 10 shows the distribution of molybdenum in heavy-mineral-concentrate samples. Samples containing 15 ppm or more molybdenum are referred to as anomalous. This corresponds to 71 samples representing the upper 10 percent of the concentrate population.

The largest cluster of anomalous molybdenum samples is in the northern part of the study area (area Mo-1). The majority of the anomalous samples occur within a 5-mile radius of Bushnell Peak. All of the samples which contain anomalous molybdenum in this area are in drainages which contain Precambrian gneiss, which suggests a relationship between the two. Two potential sources seem most likely: (1) either a high background level in the gneiss, possibly a particular unit of the gneiss, or (2) stratabound metal occurrences in the gneiss, or both. Metallization along fractures and veining in the gneiss could also contribute to the molybdenum anomalies.

Area Mo-2 contains three samples which have anomalous values of molybdenum. These three samples are all in the uppermost parts of streams draining the Rito Alto stock. The stock, which has been prospected for molybdenum mineralization, is apparently responsible for these molybdenum values.

Numerous, scattered samples contain anomalous molybdenum in the central part of the study area (area Mo-3). The source of this molybdenum is not clear. Potential contributors include high background levels in either or both the Precambrian gneiss or the Sangre de Cristo Formation, concentration along fractures, U-Cu occurrences in upper Paleozoic sedimentary rocks, Precambrian stratabound metal occurrences, or any combination of these sources.

Samples containing anomalous amounts of molybdenum in the Sand and Medano Creeks area (area Mo-4) occur in various rock types which are cut by a series of northwest-trending faults. The molybdenum is apparently related to metallization along fractured rock.

Anomalous molybdenum in the southern part of the study area (area Mo-5) is probably due to veining and (or) metallization along the northwest-trending fault system in the Blanca Peak area.

Additional molybdenum anomalies occur in Axtel Canyon and Zapata Creek and are probably related to the range front fault system in this part of the study area.

Tungsten in heavy-mineral concentrates

Three areas contain clusters of anomalous tungsten which are readily explainable. These include possible Precambrian stratabound sulfide occurrences in the northern part of the area, occurrences related to the Rito Alto stock in the vicinity of Cottonwood Peak, and veining and (or) fracture-related seepage in the southern part of the study area. In addition, numerous occurrences of scattered, isolated tungsten anomalies are not as easily explained. The source for these anomalies is not known, but probably includes either high background levels in certain rock unit(s), which may not necessarily be differentiated on the geologic map, or vein or fracture-related mineralization.

Figure 11 shows the distribution of tungsten in heavy-mineral-concentrate samples. Samples which contain 150 ppm or more tungsten are referred to as anomalous. This corresponds to 89 samples representing the upper 12 percent of the heavy-mineral-concentrate population.

The greatest concentration of samples containing anomalous amounts of tungsten is in the northern part of the study area, centered around Bushnell Peak (area W-1). Approximately 35 samples contain anomalous amounts of tungsten in this area; many contain 500 ppm or more tungsten. There is a close association between samples containing anomalous tungsten and the occurrence of sillimanite-bearing Precambrian gneiss (R. B. Taylor, personal communication). This association suggests the possibility of a genetic relationship between the Precambrian gneiss and the anomalous tungsten values. Aphanitic scheelite was identified in several samples studied with a binocular microscope, suggesting the presence of pods or lenses of scheelite-bearing rock in the Precambrian gneiss of this area.

Many of the heavy-mineral-concentrate samples in the uppermost parts of drainages peripheral to the Rito Alto stock contain anomalous tungsten (area W-2). These anomalies are probably related to the stock either as high background values in certain phases or related to metallizing processes.

Area W-3 contains three samples with anomalous amounts of tungsten. These anomalies are apparently related to vein- or fracture-controlled metallization associated with the Sangre de Cristo fault system.

Anomalous tungsten in area W-4 is apparently related to veining or metallization associated with fractured rock in the vicinity of Blanca Peak and along the range front in this area.

Area W-5 contains five samples which are anomalous in tungsten whose source is not readily explainable. Two explanations, however, seem most likely: (1) the tungsten is related to a high background level in Precambrian gneiss in this particular area, or (2) the tungsten is related to seepage along faulted rock. The first explanation is favored because of the consistency of the values, that is, there is no tailing off of the values downstream from any faults, and because of the relatively low values of the tungsten anomalies (200 ppm or less).

Anomalous tungsten in areas W-6 is characterized by relatively isolated, single "spot" anomalies which are not readily explainable. Sources which may have contributed to these anomalies include high background tungsten in a variety of rock units, veining or metallization in fractured rock, especially along the range-front fault systems, or a combination of these sources.

Tin in heavy-mineral concentrates

Tin anomalies are apparently related to several possible sources in the study area. In the northern part of the area a high concentration of anomalous tin is closely related to Precambrian gneiss and apparently represents either a very high background level in this rock or some particular unit(s) of the rock, anomalous concentration of tin in unidentified Precambrian stratabound sulfide occurrences, concentration of tin along faults and (or) fractures, or a combination of these processes. In the Cottonwood Peak area anomalous tin is apparently associated with the Rito Alto stock. In the central and south-central parts of the study area many samples contain 70-100 ppm tin and are apparently related to high background levels in Precambrian gneiss or unit(s) of the gneiss. Throughout the study area, and including the Blanca Peak area, scattered tin anomalies are associated with fault or vein-type mineralization. This type of tin localization is most prominent along either the range-front fault systems or in the quartz-vein mineralizing systems such as that found in the Blanca Peak area.

Figure 12 shows the distribution of tin in heavy-mineral-concentrate samples. Samples which contain 70 ppm or more tin will be referred to as anomalous. This corresponds to 108 samples representing the upper 15 percent of the concentrate population.

The largest cluster of samples containing anomalous amounts of tin, and some of the highest tin values in the area, is in the northern part of the study area (area Sn-1). This area is within a 5- to 6-mile radius of Hunts Peak. Almost all of the anomalous samples are from drainages which contain Precambrian gneiss, suggesting that the tin occurs either as anomalously high background levels in certain units of the gneiss, or as pods or lenses associated with possible stratabound metal deposits in the Precambrian gneiss. The tin, or some of the tin, may have also originated from metallization along faults or fractures in this area.

Anomalous tin occurs peripheral to the Rito Alto stock in area Sn-2. These tin anomalies are probably related to the Rito Alto stock and its associated metallization or background levels. However, the very high tin value (greater than 1,000 ppm) in Orient Canyon is probably related to either metallization associated with fractured rock or vein-type mineralization.

Scattered occurrences of anomalous tin occur along the eastern part of the study area from Spruce Creek to Goodwin Creek (areas Sn-3). Possible sources for this tin include high background concentrations in the Sangre de Cristo Formation and metallization along northwest-trending fault and fracture zones which bound the east edge of the range.

[illegible]

to exist about 2 miles upstream from the sample location.

Summary of heavy-mineral-concentrate geochemistry

Figure 14 is a summary map of selected trace-element anomalies in heavy-mineral-concentrate samples. It should be remembered that the map represents anomalous stream drainage samples which originated upstream from the collection sites. Therefore, the source(s) of the anomalies may lie an undetermined distance upstream from the areas outlined.

Area A is anomalous in the elements W-Sn-Mo-Cu-Pb-Zn-Ba-Bi and contains a central "barren" zone which is not anomalous in any of these elements. Several sources may have contributed to the anomalous concentrations in this area. These include suspected Precambrian stratabound metal occurrences, anomalously high background levels of any or all of the elements in a particular rock unit(s), quartz veins, metallization along fractured rock, and replacement of lower Paleozoic sedimentary rocks. Of these sources, only quartz-vein mineralization has been identified to date. However, it is thought that the Precambrian stratabound metal type of deposit has a relatively high likelihood for existence. The existence of a carbonate-replacement deposit seems unlikely.

Area B consists of an approximately semicircular area which is anomalous in two or three of the elements Cu, Pb, and Ba. The source(s) for the anomalies may include one or more of the following types of mineralization: quartz-veining, metallization along fractures, U-Cu redbed occurrences in upper Paleozoic sedimentary rocks, replacement of lower Paleozoic sedimentary rocks, and (or) mineralization associated with the Slide Rock stock. Of these mineral deposit types, quartz-veining and metallization along fractured rock seem to be the deposit types which probably account for the majority of the anomalous sample sites, particularly for the eastern and western parts of area B, along the vicinity of the Alvarado and Sangre de Cristo fault systems, respectively. None of the other mineralization types have been recognized to date in the area, yet the geochemical signature is compatible with any of these sources. The potential for metallization associated with the Slide Rock stock (that is, a porphyry-metal type of system) seems to be relatively low due to the paucity of noticeable alteration associated with the exposed part of the stock. Neither replacement in lower Paleozoic carbonate rocks or U-Cu redbed occurrences in upper Paleozoic sedimentary rocks have been identified in area B. Thus, metallization along fractured rock and quartz-veining seem to be the most likely sources for the anomalies.

Area C contains anomalous W-Mo-Sn-Bi-Pb. This area centers on the Rito Alto stock and the anomalous trace-element patterns are probably related to metallization associated with the stock. This is the only known occurrence of porphyry-type metallization in the study area. The Rito Alto stock was studied by Toulmin (1953) and has been explored via several drill holes. Apparently, the metallization associated with the stock is weakly developed, subeconomic, and (or) of limited extent.

Areas D and E are two small areas which contain anomalous trace-element abundances along major structural features, the Sangre de Cristo and Alvarado fault systems. Area D contains a more complex trace-element signature, consisting of W-Sn-Mo-Bi-Pb-Zn. This signature is apparently related to mineralization in lower Paleozoic carbonate rocks, including the Orient iron mine, and in Precambrian gneiss cut by the Sangre de Cristo fault system. Area E contains anomalous Ba and Pb and is centered on the Rita Alta copper mine.

Area F outlines an area that approximately parallels U-Cu redbed-type occurrences in upper Paleozoic sedimentary rocks. Most of area F contains anomalous amounts of one or more of the elements Cu, Pb, and Ba. These elements are apparently related to the U-Cu mineralization and are thought to be good pathfinder elements for this type of mineralization. Two exceptions to this generalization are parts of Cotton and Spring Creeks on the west side of area F which contain anomalous Sn-Pb-Ba and the northeastern part of area F which contains anomalous amounts of Cu-Pb-Zn-Ba-Bi-Sn. The most likely source for the more complex trace-element anomalies in these areas is quartz-veining or metallization along fractures, especially along the major fault systems which are present in both of these areas. It is also possible that Precambrian stratabound metal occurrences contribute some of the metals in these areas.

Area G contains anomalous abundances of Cu-Pb-Sn, with sporadic occurrences of anomalous amounts of Mo, and (or) Zn. The source(s) of the anomalies in area G is not readily explainable. Three sources seem most likely, including unusually high background values of any or all of these elements, probably in a unit or units of Precambrian gneiss, stratabound metal occurrences in Precambrian gneiss, and (or) metallization along fractured rock.

Area H contains anomalous amounts of Ba and (or) Cu. The source for these anomalies is not known because it is outside the study area boundaries and has not received detailed geologic mapping.

Area I contains anomalous amounts of W-Sn-Mo-Cu-Pb. Anomalies in area I are apparently related to a strongly developed quartz-vein system which trends northwesterly and is well exposed on the north face of Blanca Peak. A semicircular area west of Blanca Peak which contains anomalous amounts of copper could be related to disseminated chalcopyrite identified in Precambrian rocks in this area. Also, a small area near the base of the range including Holbrook Creek and Chokecherry and Chimney Gulches contains anomalous W-Sn-Cu and is probably related to metallization associated with a range-front fault.

ROCK GEOCHEMISTRY

Rock samples were generally collected to represent altered or mineralized rocks at mines or prospects, or "different rocks" such as pegmatites, dikes, or stained rocks, and do not represent a thorough or systematic sampling of the study area. Therefore, the rock data should be used in conjunction with the stream-deposit data, and should not be considered comprehensive on its own.

A summary map of selected elements, including Au, Ag, Pb, Zn, Cu, Mo, Ba, Bi, As, Sb, and W, in rock samples is shown on figure 15. A brief discussion of these elements follows.

Gold in rock samples

Gold was found in abundances of 10 ppm or more in six rock samples. Three of the samples are from quartz-vein samples in Precambrian gneiss in the Pole Creek drainage basin. One of the gold-bearing samples is from a quartz vein exposed on the north face of Blanca Peak, one is from a quartz vein in Carr Gulch, and one is from a quartz vein in Precambrian gneiss near Spanish Creek and the Independence Mine.

Silver in rock samples

Silver occurs in abundances of 5 ppm or more in 17 rock samples. Most of the silver-bearing samples are from quartz veins associated with northwest-trending faults. The veins are hosted by a variety of rock types including Precambrian gneiss and metadiorite and upper Paleozoic sedimentary rocks.

Lead in rock samples

Lead occurs in abundances of 200 ppm or more in 12 rock samples. These samples include a wide variety of rock types including Precambrian-hosted pegmatites, Precambrian granodiorite and amphibolite, quartz veins, and lower Paleozoic carbonate rocks. All samples which contain 200 ppm or more lead are located north of Sand Creek.

Zinc in rock samples

Zinc occurs in abundances of 200 ppm or more in 10 rock samples. Anomalous zinc is found in an assortment of rock types in the study area, but is confined to an area north of Taylor Creek. Rock types which contain anomalous zinc include quartz veins, pegmatites, lower Paleozoic carbonates and quartzites, and tonalite from the Rito Alto stock.

Copper in rock samples

Copper occurs in abundances of 500 ppm or more in 34 rock samples. These samples are scattered throughout the study area and are from a variety of rock types, including U-Cu redbed occurrences, quartz veins, Precambrian amphibolite, skarn, and [illegible] associated with the Rito Alto stock.

Molybdenum in rock samples

Molybdenum occurs in abundances of 5 ppm or more in 26 rock samples. The greatest concentration of rock samples containing anomalous amounts of molybdenum is in the Rito Alto stock area. Rock samples from the stock which contain anomalous molybdenum include granite, quartz monzonite, rhyolite, and quartz veins. Other samples containing anomalous molybdenum occur throughout much of the study area, generally in quartz veins located near regional-scale, northwest-trending fault systems.

Barium in rock samples

Barium occurs in abundances of greater than 5,000 ppm in eight rock samples. Four of these samples are located in the Rito Alto stock, three are peripheral to the stock (one at the Rita Alta mine and two in Hot Springs Canyon), and one is in Hayden Pass Creek drainage. The close association between anomalous barium and the Rito Alto stock suggests a genetic relationship between the two.

Other elements in rock samples

Bismuth, arsenic, antimony, and tungsten are included on the rock geochemistry summary map but are not discussed individually. Generally, these elements occur in detectable quantities in a very limited number of samples in the study area and little is known about their relationship with the different types of mineral deposit types found in the area.

Summary of rock geochemistry

Copper and molybdenum are found in a variety of rock types scattered throughout much of the study area. Barium is generally confined to the vicinity of the Rito Alto stock and is thought to be genetically related to the stock. Lead and zinc are found in anomalous amounts in a variety of rock types, but the anomalies are confined to the northern half of the study area. Silver occurs throughout much of the study area, generally in quartz veins associated with northwest-trending structural elements. Gold is confined to quartz veins hosted by Precambrian gneiss and apparently localized by northwest-trending structures.

SUMMARY

The geochemical interpretations presented here are based on stream drainage samples collected from first- and second-order drainages supplemented by scattered rock samples collected mostly at prospect pits and mines.

The area around Bushnell Peak in the northern part of the study area may contain Precambrian stratabound metal occurrences. Although not yet recognized within the study area, this type of deposit does occur in similar rocks in nearby areas. If this type of mineral deposit does exist, it probably occurs as small, discontinuous, scattered lenses and (or) pods. The Bushnell Peak area contains some of the highest values and some of the largest clusters of anomalous samples in the study area, including anomalies in the elements W-Sn-Mo-Cu-Pb-Zn-Ba-Bi in heavy-mineral-concentrate samples and Ag-Pb-Zn-Cu-As-Sb-Bi-Ba-Mo in rock samples.

South of Bushnell Peak, in the vicinity of Cottonwood Peak, metallization associated with the Rito Alto stock produced trace-element anomalies in the elements W-Mo-Sn-Bi-Pb-Ba in heavy-mineral-concentrate samples and Mo-Cu-Pb-Zn-Ba-Bi in rock samples.

Between Cottonwood and Bushnell Peaks, especially near the range fronts, metallization associated with either quartz-veining or fractured rock produced both simple and complex trace-element anomaly signatures in the suite of elements Cu-Pb-Zn-Ba-W-Sn-Mo-Bi in heavy-mineral-concentrate samples and Au-Ag-Ba-Bi-Cu-Pb-Zn in rock samples.

Much of the central part of the study area is characterized by anomalous amounts of one or more of the elements Cu, Pb, and Ba in heavy-mineral-concentrate samples. Anomalous abundances of these elements outline the occurrence of U-Cu redbed mineralization in upper Paleozoic sedimentary rocks.

In the vicinity of Blanca Peak, quartz-vein mineralization associated with a northwest-trending fault system produced anomalies in heavy-mineral-concentrate samples of W-Sn-Mo-Cu-Pb and Au-Ag-Bi-Cu-Mo in rock samples. Disseminated chalcopyrite in Precambrian igneous rocks may be responsible for some of the Cu anomalies in the Blanca Peak area.

Throughout much of the study area, especially in the vicinity of the range front but not necessarily confined to it, geochemical anomalies, including W-Mo-Sn-Cu-Pb-Zn in heavy-mineral-concentrate samples and Au-Ag-W-Mo-Cu-Pb-Zn-Ba-Bi in rock samples, are probably related to metallization along fractured rock.

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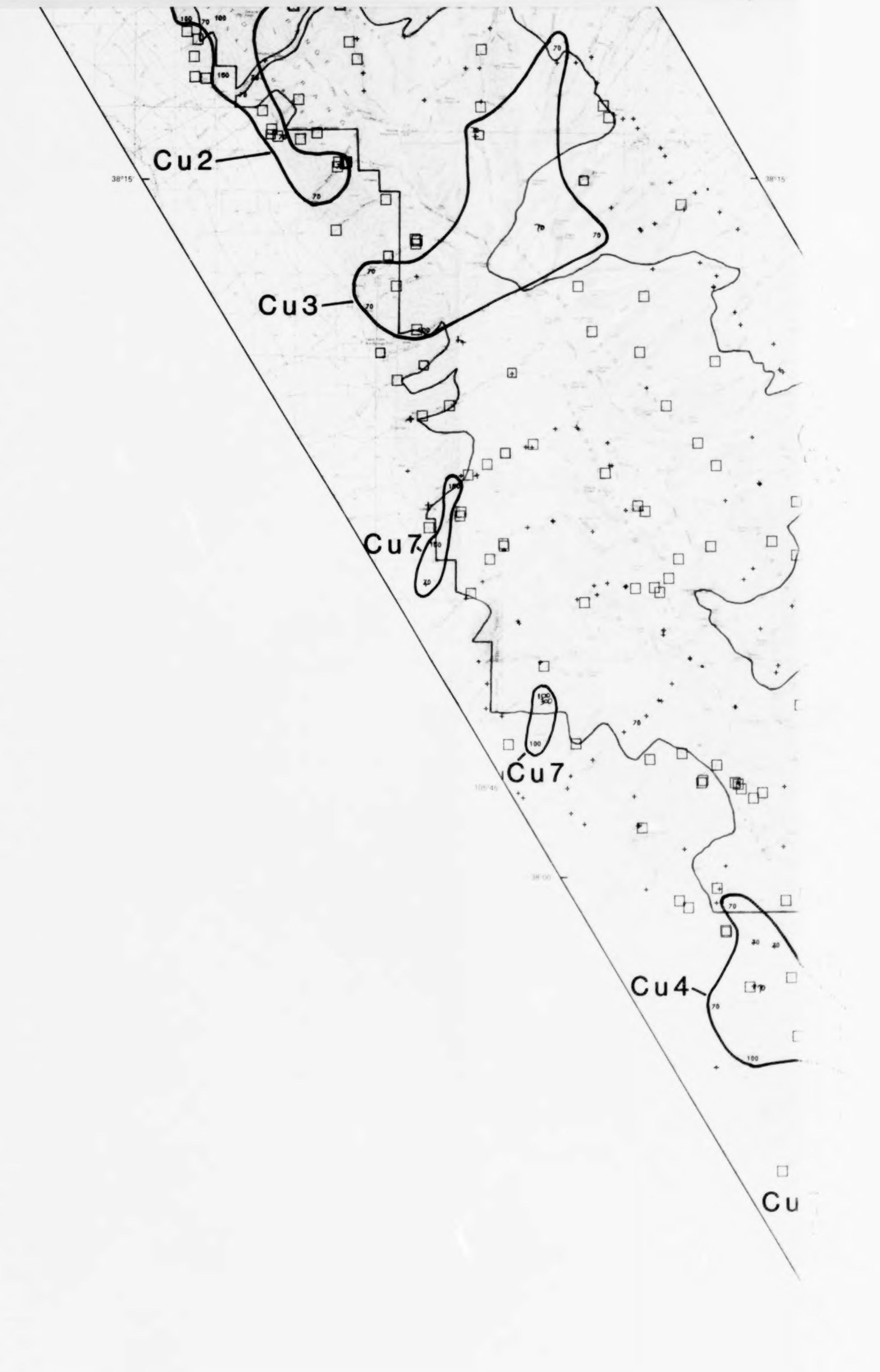


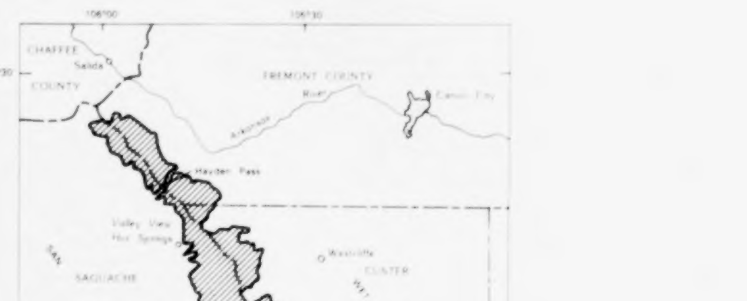
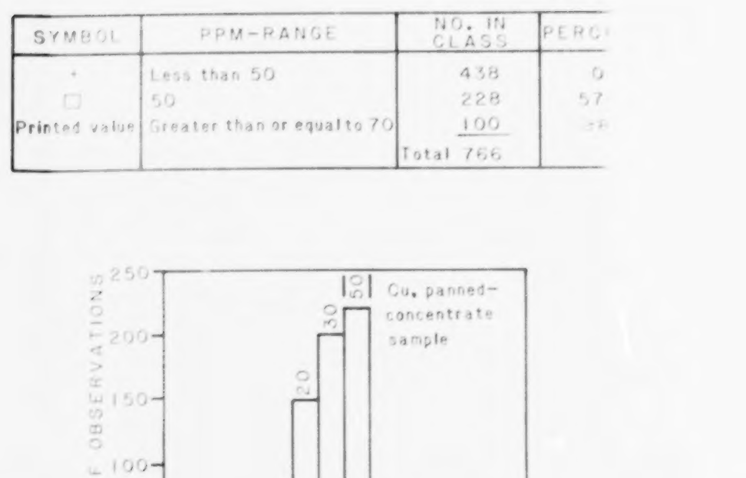


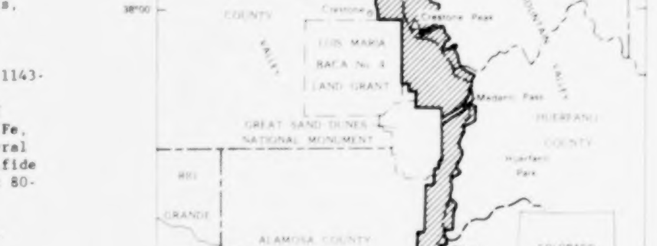
Figure 1.--Map showing location of Sangre de Cristo Wilderness Study Area (diagonally ruled), Colorado.

EXPLANATION FOR FIGURE 2

SYMBOL	PPM-RANGE	NO. IN CLASS	PERC
+	Less than 50	438	[illegible]
□	50	228	57
Printed value	Greater than or equal to 70	100	[illegible]
		Total 766	



Area containing anomalous concentrations of Cu- Referred to in text



CONTOUR INTERVAL 80 FEET

NATIONAL GEODETIC VERTICAL DATUM OF 1929

MAPS SHOWING TRACE-ELEMENT GEOCHEMISTRY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA, SOUTH-CENTRAL COLORADO

By

David R. Zimbelman

1989

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Summary of heavy-mineral-concentrate geochemistry

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ROCK GEOCHEMISTRY

Rock samples were generally collected to represent altered or mineralized rocks at mines or prospects, or "different rocks" such as pegmatites, dikes, or stained rocks, and do not represent a thorough or systematic sampling of the study area. Therefore, the rock data should be used in conjunction with the stream-deposit data, and should not be considered comprehensive on its own.

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Molybdenum occurs in abundances of 5 ppm or more in 26 rock samples. The greatest concentration of rock samples containing anomalous amounts of molybdenum is in the Rito Alto stock area. Rock samples from the stock which contain anomalous molybdenum include tonalite, quartz-monzonite, rhyolite, and quartz veins. Other samples containing anomalous molybdenum occur throughout much of the study area, generally in quartz veins located near regional-scale, northwest-trending fault systems.

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Barium occurs in abundances of greater than 5,000 ppm in eight rock samples. Four of these samples are located in the Rito Alto stock, three are peripheral to the stock (one at the Rita Alta mine and two in Hot Springs Canyon), and one is in Hayden Pass Creek drainage. The close association between anomalous barium and the Rito Alto stock suggests a genetic relationship between the two.

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Copper and molybdenum are found in a variety of rock types scattered throughout much of the study area. Barium is generally confined to the vicinity of the Rito Alto stock and is thought to be genetically related to the stock. Lead and zinc are found in anomalous amounts in a variety of rock types, but the anomalies are confined to the northern half of the study area. Silver occurs throughout much of the study area, generally in quartz veins associated with northwest-trending structural elements. Gold is confined to quartz veins hosted by Precambrian gneiss and apparently localized by northwest-trending structures.

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South of Bushnell Peak, in the vicinity of Cottonwood Peak, metallization associated with the Rito Alto stock produced trace-element anomalies in the elements W-Mo-Sn-Bi-Pb-Ba in heavy-mineral-concentrate samples and Mo-Cu-Pb-Zn-Ba-Bi in rock samples.

Between Cottonwood and Bushnell Peaks, especially near the range fronts, metallization associated with either quartz-veining or fractured rock produced both simple and complex trace-element anomaly signatures in the suite of elements Cu-Pb-Zn-Ba-W-Sn-Mo-Bi in heavy-mineral-concentrate samples and Au-Ag-Ba-Bi-Cu-Pb-Zn in rock samples.

Much of the central part of the study area is characterized by anomalous amounts of one or more of the elements Cu, Pb, and Ba in heavy-mineral-concentrate samples. Anomalous abundances of these elements outline the occurrence of U-Cu redbed mineralization in upper Paleozoic sedimentary rocks.

In the vicinity of Blanca Peak, quartz-vein mineralization associated with a northwest-trending fault system produced anomalies in heavy-mineral-concentrate samples of W-Sn-Mo-Cu-Pb and Au-Ag-Bi-Cu-Mo in rock samples. Disseminated chalcopyrite in Precambrian igneous rocks may be responsible for some of the Cu anomalies in the Blanca Peak area.

Throughout much of the study area, especially in the vicinity of the range front but not necessarily confined to it, geochemical anomalies, including W-Mo-Sn-Cu-Pb-Zn in heavy-mineral-concentrate samples and Au-Ag-W-Mo-Cu-Pb-Zn-Ba-Bi in rock samples, are probably related to metallization along fractured rock.

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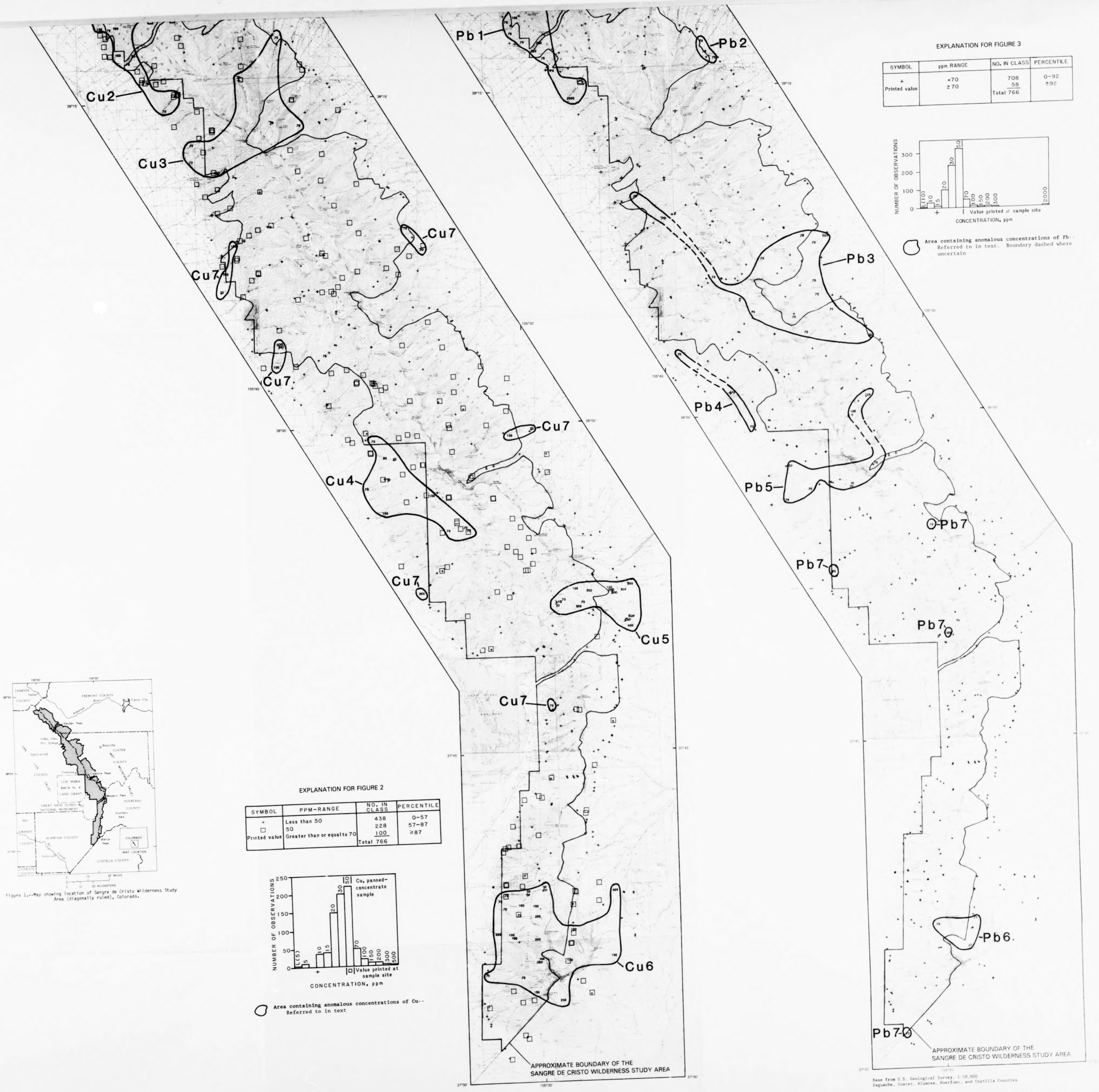

Figure 1.--Map showing location of Sangre de Cristo Wilderness Study Area (diagonally ruled), Colorado.

EXPLANATION FOR FIGURE 2

SYMBOL	PPM-RANGE	NO. IN CLASS	PERCENTILE
+	Less than 50	438	0-57
□	50	228	57-87
Printed value	Greater than or equal to 70	100	≥87
		Total 766	

Area containing anomalous concentrations of Cu--Referred to in text

FIGURE 2--Cu IN STREAM-SEDIMENT SAMPLES

EXPLANATION FOR FIGURE 3

SYMBOL	ppm RANGE	NO. IN CLASS	PERCENTILE
+	<70	708	0-92
Printed value	≥70	58	≥92
		Total 766	

Area containing anomalous concentrations of Pb--Referred to in text. Boundary dashed where uncertain

Base from U.S. Geological Survey, 1:50,000
Saguache, Custer, Alamosa, Huerfano, and Costilla Counties

FIGURE 3.--Pb IN STREAM-SEDIMENT SAMPLES

SCALE 1:125 000
2 0 2 4 6 8 MILES
2 0 2 4 6 8 KILOMETERS

CONTOUR INTERVAL 80 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

MAPS SHOWING TRACE-ELEMENT GEOCHEMISTRY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA, SOUTH-CENTRAL COLORADO

By
David R. Zimbelman
1989

Manuscript approved for publication, June 15, 1988

Any use of trade names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey

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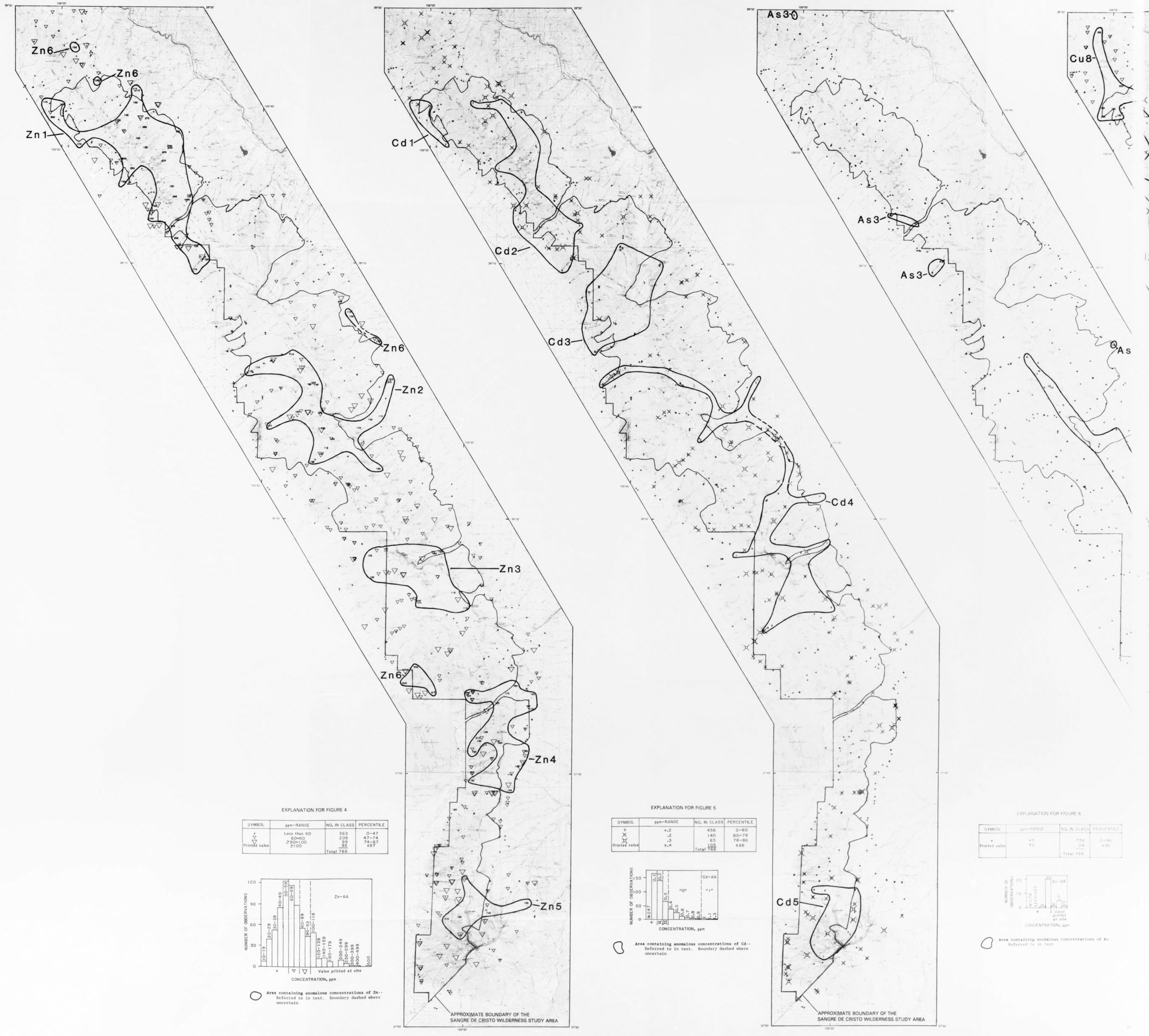
MISCELLANEOUS FIELD STUDIES
MAP MF-1635-C
SHEET 2 OF 4


Zn6
Zn6
Zn1
Zn6
Zn2
Zn3
Zn6
Zn4
Zn5
Cd1
Cd2
Cd3
Cd4
Cd5
As3
As3
As3
As
Cu8
Zn-AA
NUMBER OF OBSERVATIONS
CONCENTRATION, ppm
Value printed at site
Cd-AA
"0"
"1"
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA

EXPLANATION FOR FIGURE 4

SYMBOL	ppm-RANGE	NO. IN CLASS	PERCENTILE
+	Less than 60	363	0-47
▽	60<80	208	47-74
▽	≥80<100	99	74-87
Printed value	≥100	96	≥87
		Total 766	

Area containing anomalous concentrations of Zn--Referred to in text. Boundary dashed where uncertain

FIGURE 4.–Zn IN STREAM-SEDIMENT SAMPLES

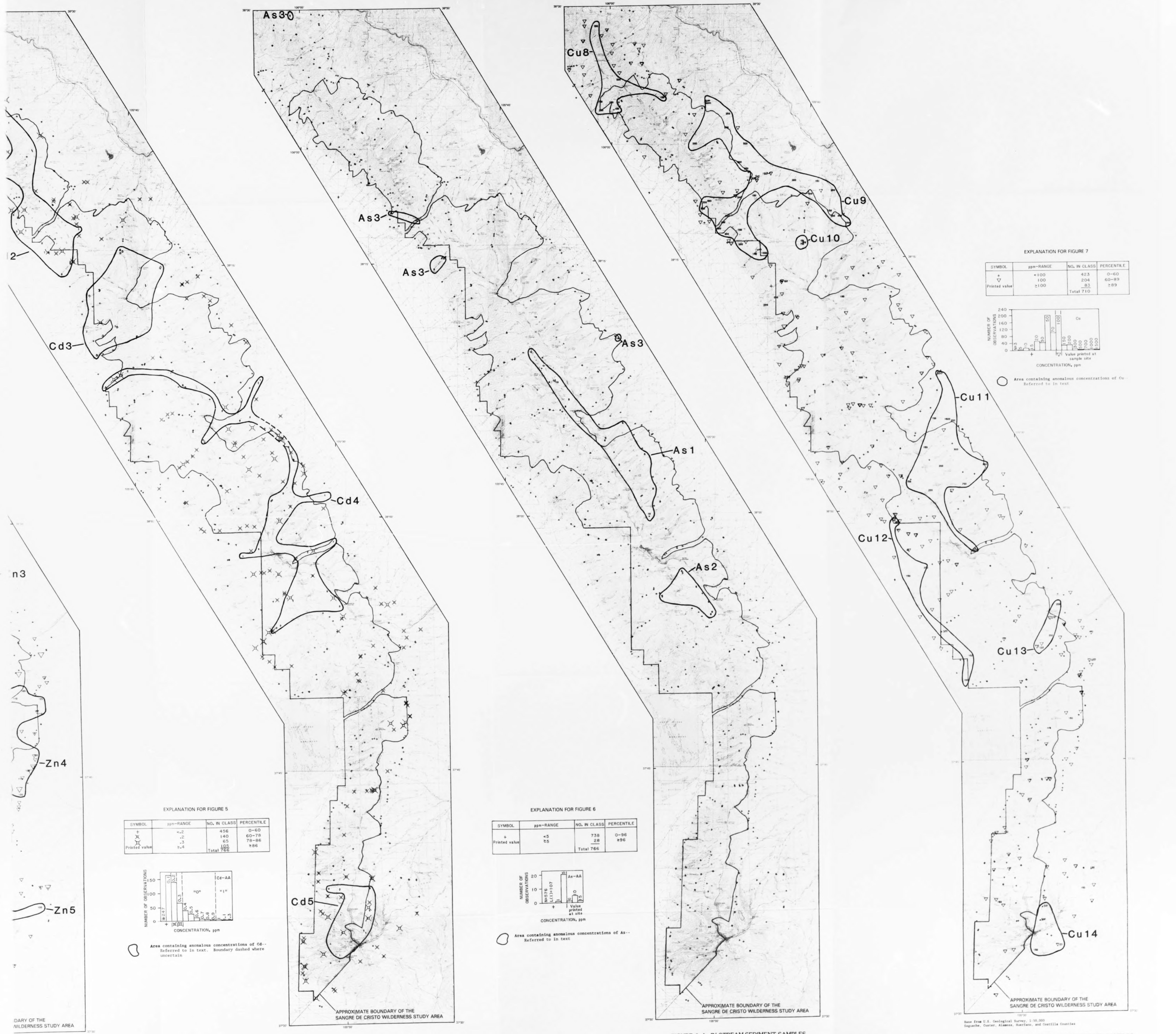
EXPLANATION FOR FIGURE 5

SYMBOL	ppm-RANGE	NO. IN CLASS	PERCENTILE
+	<.2	456	0-60
⌧	.2	140	60-78
⌧	.3	65	78-86
Printed value	≥.4	105	≥86
		Total 766	

Area containing anomalous concentrations of Cd--Referred to in text. Boundary dashed where uncertain

APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA

FIGURE 5.–Cd IN STREAM-SEDIMENT SAMPLES


2
Cd3
n3
Zn4
Zn5
As3
As3
As3
As3
As1
As2
Cd4
Cd5
Cu8
Cu9
Cu10
Cu11
Cu12
Cu13
Cu14
As-AA
N=576
L(1)=107
Value printed at site
CONCENTRATION, ppm
NUMBER OF OBSERVATIONS
Cu
N=3
Value printed at sample site
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA

EXPLANATION FOR FIGURE 5

SYMBOL	ppm-RANGE	NO. IN CLASS	PERCENTILE
+	<.2	456	0-60
⌧	.2	140	60-78
⌧	.3	65	78-86
Printed value	≥.4	105	≥86
		Total 766	

Area containing anomalous concentrations of Cd--Referred to in text. Boundary dashed where uncertain

FIGURE 5.–Cd IN STREAM-SEDIMENT SAMPLES

EXPLANATION FOR FIGURE 6

SYMBOL	ppm-RANGE	NO. IN CLASS	PERCENTILE
+	<5	738	0-96
Printed value	≥5	28	≥96
		Total 766	

Area containing anomalous concentrations of As--Referred to in text

FIGURE 6.–As IN STREAM-SEDIMENT SAMPLES

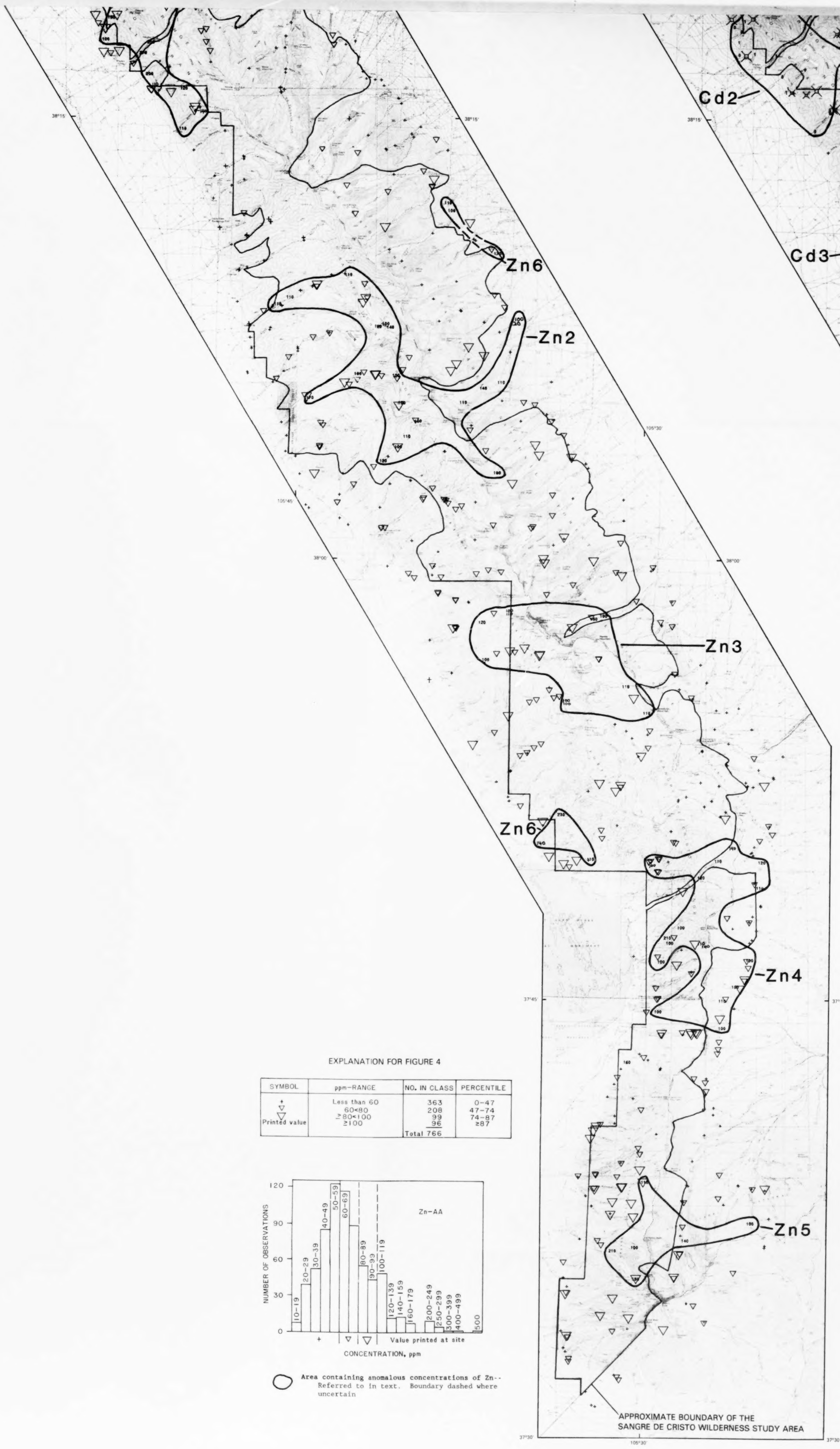
EXPLANATION FOR FIGURE 7

SYMBOL	ppm-RANGE	NO. IN CLASS	PERCENTILE
+	<100	423	0-60
▽	100	204	60-89
Printed value	≥100	83	≥89
		Total 710	

Area containing anomalous concentrations of Cu--Referred to in text

Base from U.S. Geological Survey, 1:[illegible]
Saguache, Custer, Alamosa, Huerfano, and Costilla Counties

FIGURE 7.–Cu IN HEAVY-MINERAL-CONCENTRATE SAMPLES


Zn6
Zn2
Zn3
Zn6
Zn4
Zn5
38°15'
38°00'
37°45'
37°30'
105°45'
105°30'
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA

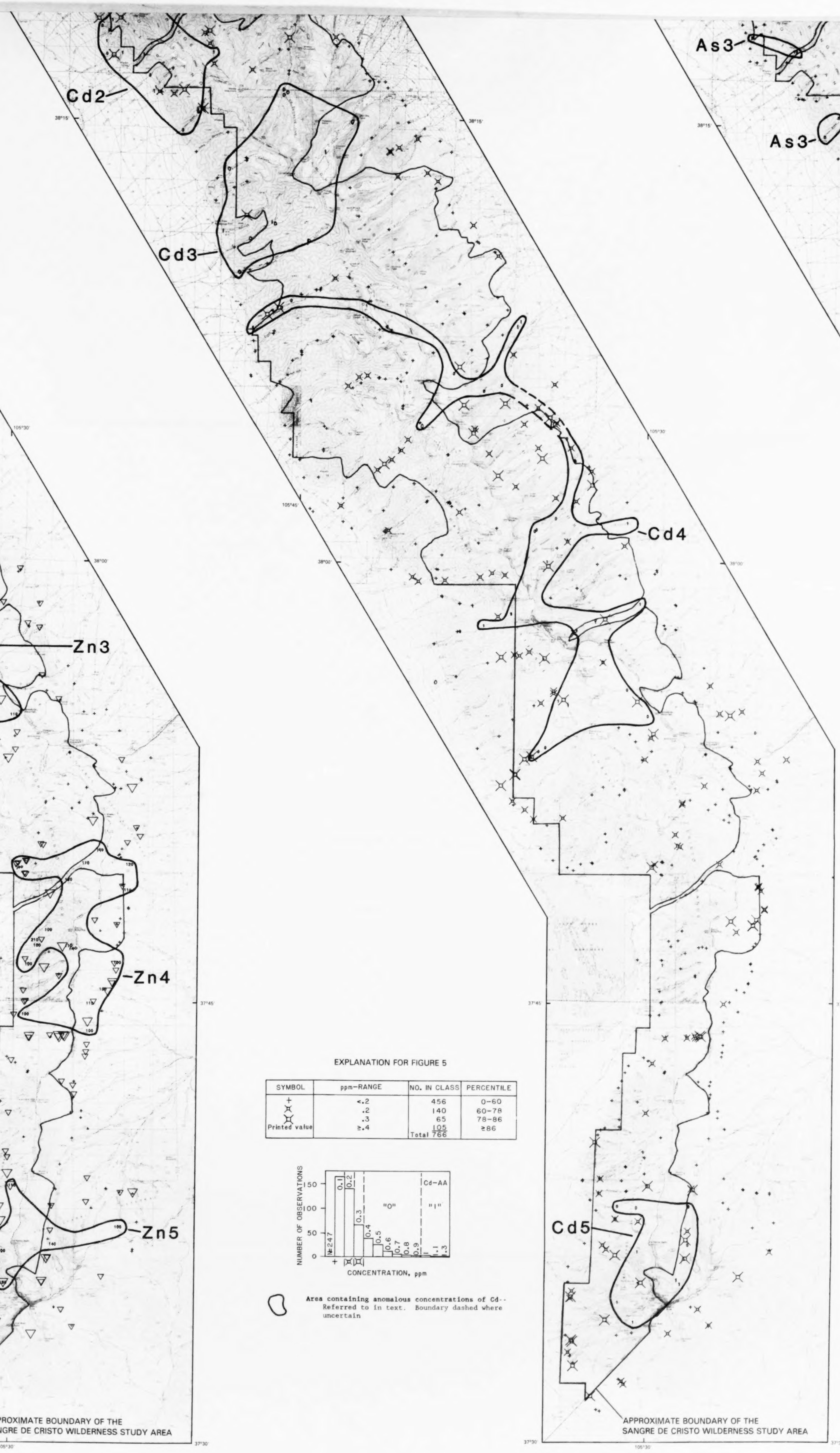
EXPLANATION FOR FIGURE 4

SYMBOL	ppm–RANGE	NO. IN CLASS	PERCENTILE
+	Less than 60	363	0–47
▽	60<80	208	47–74
▽	≥80<100	99	74–87
Printed value	≥100	96	≥87
		Total 766	

120
90
60
30
0
NUMBER OF OBSERVATIONS
Zn–AA
10–19
20–29
30–39
40–49
50–59
60–69
80–89
90–99
100–119
120–139
140–159
160–179
200–249
250–299
300–399
400–499
500
+
▽
▽
Value printed at site
CONCENTRATION, ppm

Area containing anomalous concentrations of Zn-- Referred to in text. Boundary dashed where uncertain

FIGURE 4.–Zn IN STREAM-SEDIMENT SAMPLES


Cd2
Cd3
Cd4
Cd5
38°15'
38°00'
37°45'
37°30'
105°45'
105°30'
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA

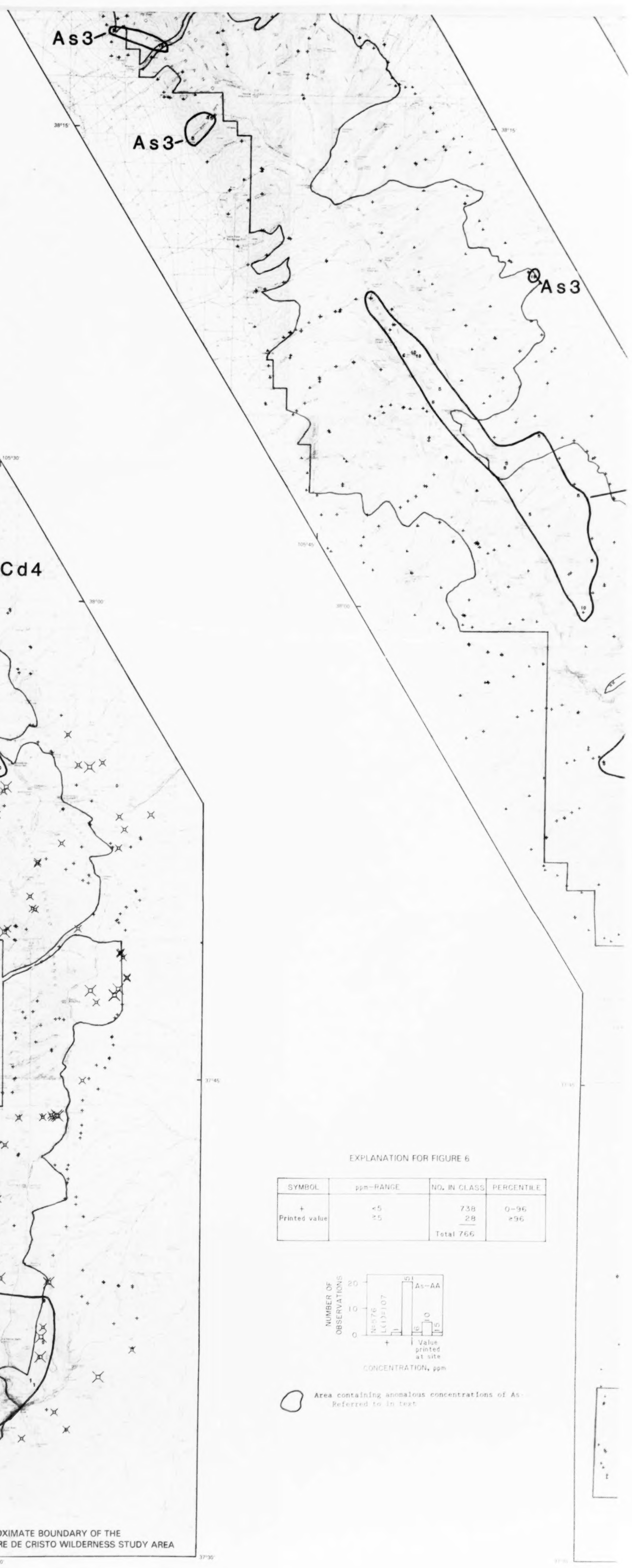
EXPLANATION FOR FIGURE 5

SYMBOL	ppm–RANGE	NO. IN CLASS	PERCENTILE
+	<.2	456	0–60
⌑	.2	140	60–78
⌑	.3	65	78–86
Printed value	≥.4	105	≥86
		Total 766	

150
100
50
0
NUMBER OF OBSERVATIONS
N=247
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.3
"0"
"1"
Cd–AA
+
CONCENTRATION, ppm

Area containing anomalous concentrations of Cd-- Referred to in text. Boundary dashed where uncertain

FIGURE 5.–Cd IN STREAM-SEDIMENT SAMPLES


As3
As3
As3

EXPLANATION FOR FIGURE 6

SYMBOL	ppm–RANGE	NO. IN CLASS	PERCENTILE
+	<5	738	0–96
Printed value	≥5	28	≥96
		Total 766	

20
10
0
NUMBER OF OBSERVATIONS
N=576
L(1)=107
20
1
6
10
5
As–AA
+
Value printed at site
CONCENTRATION, ppm

Area containing anomalous concentrations of As-- Referred to in text

SCALE 1:125 000

2 0 2 4 6 8 MILES

2 0 2 4 6 8 KILOMETERS

CONTOUR INTERVAL 80 FEET

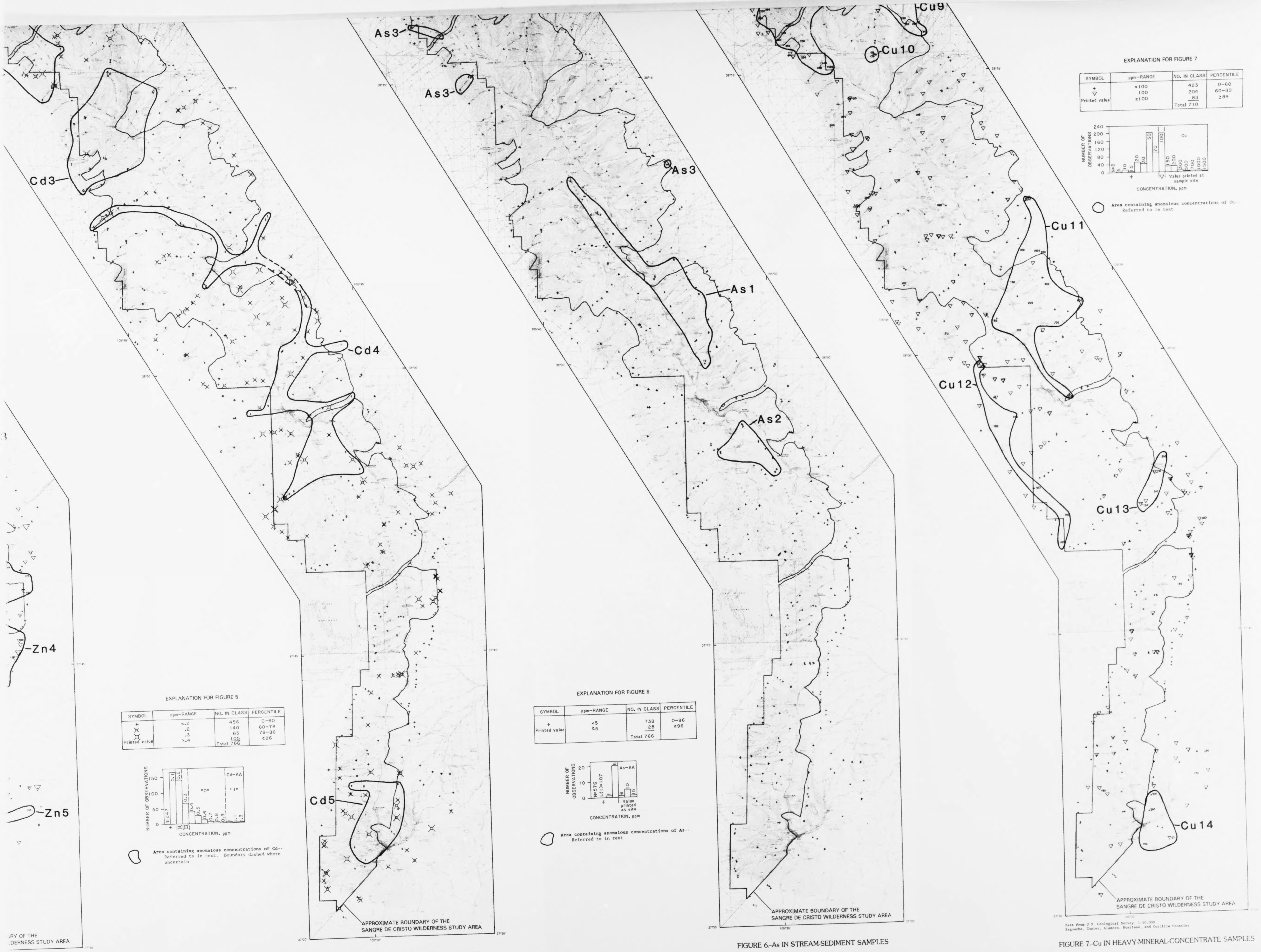
NATIONAL GEODETIC VERTICAL DATUM OF 1929

MAPS SHOWING TRACE-ELEMENT GEOCHEMISTRY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA, SOUTH-CENTRAL COLORADO

By

David R. Zimbelman

1989


Zn4
Zn5
ARY OF THE
LDERNESS STUDY AREA
Cd3
Cd4
Cd5
APPROXIMATE BOUNDARY OF THE
SANGRE DE CRISTO WILDERNESS STUDY AREA
NUMBER OF OBSERVATIONS
CONCENTRATION, ppm
Cd-AA
"0"
"1"
N=247
As3
As1
As2
APPROXIMATE BOUNDARY OF THE
SANGRE DE CRISTO WILDERNESS STUDY AREA
N=576
L(1)=107
As-AA
Value printed at site
Cu9
Cu10
Cu11
Cu12
Cu13
Cu14
APPROXIMATE BOUNDARY OF THE
SANGRE DE CRISTO WILDERNESS STUDY AREA
N=3
Cu
Value printed at sample site
37°30′
105°30′
37°45′
38°00′
38°15′
105°45′

EXPLANATION FOR FIGURE 5

SYMBOL	ppm–RANGE	NO. IN CLASS	PERCENTILE
+	<.2	456	0–60
⌑	.2	140	60–78
⌑	.3	65	78–86
Printed value	≥.4	105	≥86
		Total 766	

Area containing anomalous concentrations of Cd--Referred to in text. Boundary dashed where uncertain

FIGURE 5.–Cd IN STREAM-SEDIMENT SAMPLES

EXPLANATION FOR FIGURE 6

SYMBOL	ppm–RANGE	NO. IN CLASS	PERCENTILE
+	<5	738	0–96
Printed value	≥5	28	≥96
		Total 766	

Area containing anomalous concentrations of As--Referred to in text

FIGURE 6.–As IN STREAM-SEDIMENT SAMPLES

EXPLANATION FOR FIGURE 7

SYMBOL	ppm–RANGE	NO. IN CLASS	PERCENTILE
+	<100	423	0–60
▽	100	204	60–89
Printed value	≥100	83	≥89
		Total 710	

Area containing anomalous concentrations of Cu--Referred to in text

Base from U.S. Geological Survey, 1:50,000
Saguache, Custer, Alamosa, Huerfano, and Costilla Counties

FIGURE 7.–Cu IN HEAVY-MINERAL-CONCENTRATE SAMPLES

DIMENT SAMPLES

SCALE 1:125 000

CONTOUR INTERVAL 80 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

MAPS SHOWING TRACE-ELEMENT GEOCHEMISTRY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA, SOUTH-CENTRAL COLORADO

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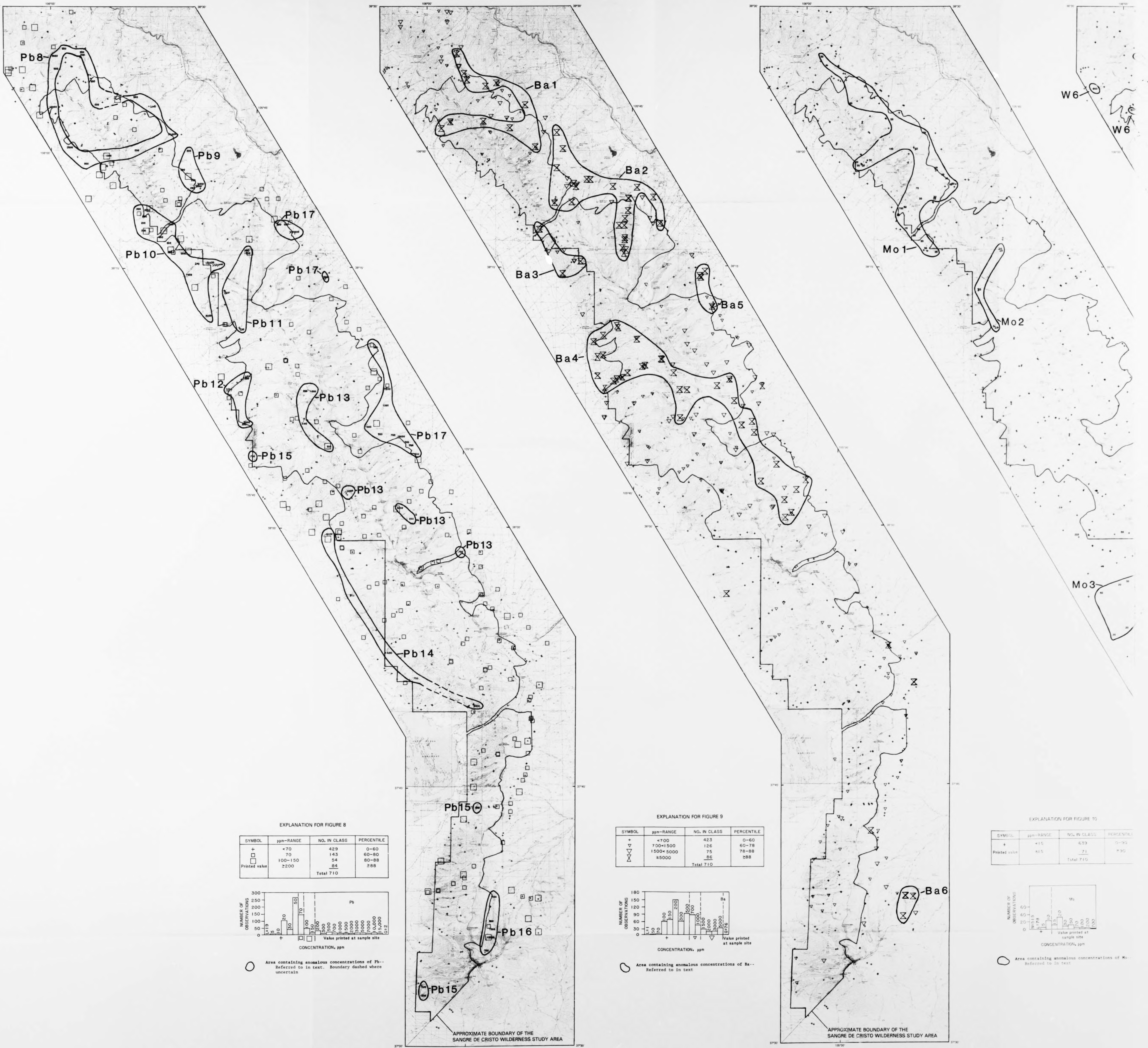

38°30'
106°00'
105°45'
38°15'
38°00'
37°45'
37°30'
105°30'
Pb8
Pb9
Pb10
Pb11
Pb12
Pb13
Pb14
Pb15
Pb16
Pb17
Ba1
Ba2
Ba3
Ba4
Ba5
Ba6
Mo1
Mo2
Mo3
W6
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA
NUMBER OF OBSERVATIONS
300
250
200
150
100
50
0
L=19
5
10
20
30
50
70
100
150
200
300
500
700
1000
1500
2000
3000
5000
7000
10,000
15,000
G=2
Pb
Value printed at sample site
CONCENTRATION, ppm
180
150
120
90
60
30
0
L=1
50
70
100
150
200
300
500
700
1000
1500
2000
3000
5000
G=76
Ba
Value printed at sample site
CONCENTRATION, ppm
60
40
20
0
N=515
L=78
5
10
15
20
30
50
70
100
200
700
Mo
Value printed at sample site
CONCENTRATION, ppm
SCALE 1:125 000

EXPLANATION FOR FIGURE 8

SYMBOL	ppm-RANGE	NO. IN CLASS	PERCENTILE
+	<70	429	0-60
□	70	143	60-80
□	100-150	54	80-88
Printed value	≥200	84	≥88
		Total 710	

Area containing anomalous concentrations of Pb--Referred to in text. Boundary dashed where uncertain

FIGURE 8.-Pb IN HEAVY-MINERAL-CONCENTRATE SAMPLES

EXPLANATION FOR FIGURE 9

SYMBOL	ppm-RANGE	NO. IN CLASS	PERCENTILE
+	<700	423	0-60
▽	700<1500	126	60-78
▽	1500<5000	75	78-88
⧗	≥5000	86	≥88
		Total 710	

Area containing anomalous concentrations of Ba--Referred to in text

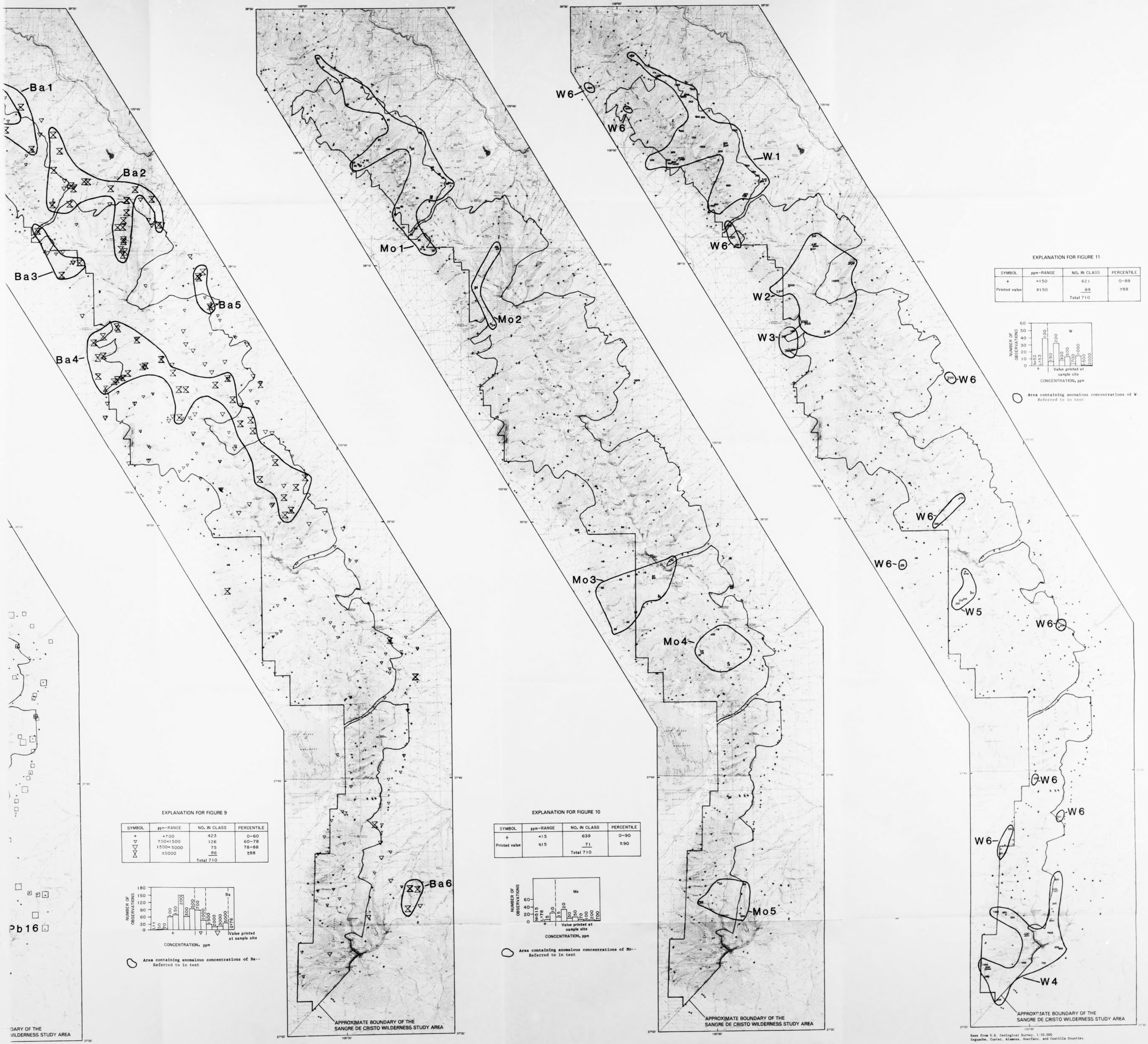
FIGURE 9.-Ba IN HEAVY-MINERAL-CONCENTRATE SAMPLES

EXPLANATION FOR FIGURE 10

SYMBOL	ppm-RANGE	NO. IN CLASS	PERCENTILE
+	<15	639	0-90
Printed value	≥15	71	≥90
		Total 710	

Area containing anomalous concentrations of Mo--Referred to in text

MISCELLANEOUS FIELD STUDIES
MAP MF-1635-C
SHEET 3 OF 4


Pb16
DARY OF THE
WILDERNESS STUDY AREA
Ba1
Ba2
Ba3
Ba4
Ba5
Ba6
APPROXIMATE BOUNDARY OF THE
SANGRE DE CRISTO WILDERNESS STUDY AREA
Mo1
Mo2
Mo3
Mo4
Mo5
APPROXIMATE BOUNDARY OF THE
SANGRE DE CRISTO WILDERNESS STUDY AREA
W1
W2
W3
W4
W5
W6
APPROXIMATE BOUNDARY OF THE
SANGRE DE CRISTO WILDERNESS STUDY AREA
38°30'
106°00'
105°45'
38°15'
105°30'
38°00'
37°45'
37°30'
105°30'

CONCENTRATE SAMPLES

EXPLANATION FOR FIGURE 9

SYMBOL	ppm-RANGE	NO. IN CLASS	PERCENTILE
+	<700	423	0-60
▽	700<1500	126	60-78
▽	1500<5000	75	78-88
⧗	≥5000	86	≥88
		Total 710	

Ba
NUMBER OF OBSERVATIONS
180
150
120
90
60
30
0
L=1
50
70
100
150
200
300
500
700
1000
1500
2000
3000
5000
G=76
+
▽
▽
Value printed at sample site
CONCENTRATION, ppm

Area containing anomalous concentrations of Ba--Referred to in text

FIGURE 9.-Ba IN HEAVY-MINERAL-CONCENTRATE SAMPLES

EXPLANATION FOR FIGURE 10

SYMBOL	ppm-RANGE	NO. IN CLASS	PERCENTILE
+	<15	639	0-90
Printed value	≥15	71	≥90
		Total 710	

Mo
NUMBER OF OBSERVATIONS
60
40
20
0
N=515
L=78
5
10
15
20
30
50
70
100
200
700
+
Value printed at sample site
CONCENTRATION, ppm

Area containing anomalous concentrations of Mo--Referred to in text

FIGURE 10.-Mo IN HEAVY-MINERAL-CONCENTRATE SAMPLES

EXPLANATION FOR FIGURE 11

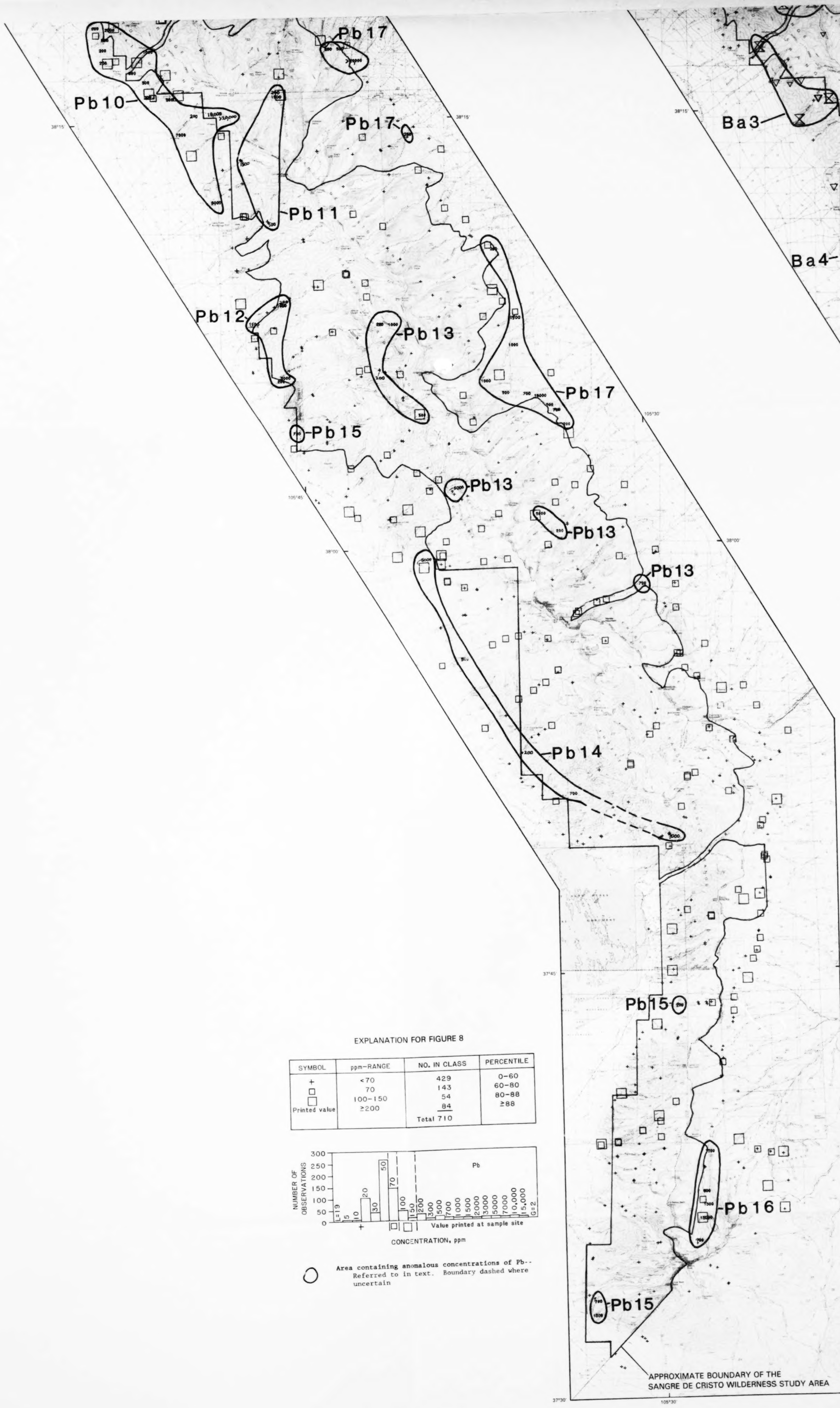
SYMBOL	ppm-RANGE	NO. IN CLASS	PERCENTILE
+	<150	621	0-88
Printed value	≥150	89	≥88
		Total 710	

W
NUMBER OF OBSERVATIONS
60
50
40
30
20
10
0
N=52
L=53
100
150
200
300
500
700
1000
1500
2000
+
Value printed at sample site
CONCENTRATION, ppm

Area containing anomalous concentrations of W--Referred to in text

Base from U.S. Geological Survey, 1:50,000
Saguache, Custer, Alamosa, Huerfano, and Costilla Counties

FIGURE 11.-W IN HEAVY-MINERAL-CONCENTRATE SAMPLES


Pb10
Pb17
Pb17
Pb11
Pb12
Pb13
Pb17
Pb15
Pb13
Pb13
Pb13
Pb14
Pb15
Pb16
Pb15
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA
37°45'
37°30'
105°30'
105°45'
38°00'
38°15'

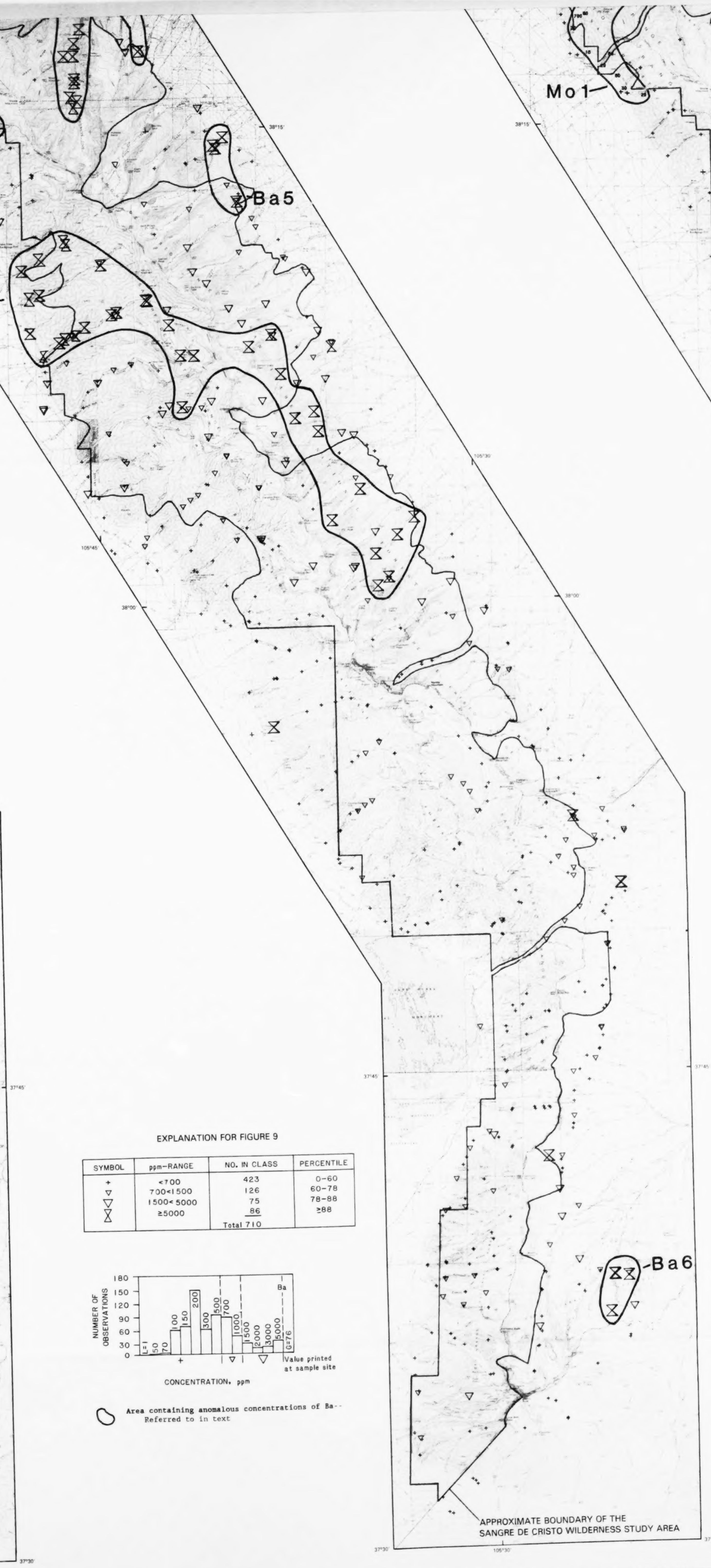
EXPLANATION FOR FIGURE 8

SYMBOL	ppm-RANGE	NO. IN CLASS	PERCENTILE
+	<70	429	0-60
□	70	143	60-80
□	100-150	54	80-88
Printed value	≥200	84	≥88
		Total 710	

NUMBER OF OBSERVATIONS
300
250
200
150
100
50
0
Pb
L=19
5
10
20
30
50
70
100
150
200
300
500
700
1000
1500
2000
3000
5000
7000
10,000
15,000
G=2
+
Value printed at sample site
CONCENTRATION, ppm

Area containing anomalous concentrations of Pb--Referred to in text. Boundary dashed where uncertain

FIGURE 8.-Pb IN HEAVY-MINERAL-CONCENTRATE SAMPLES


Ba3
Ba5
Ba4
Ba6
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA
37°45'
37°30'
105°30'
38°00'
38°15'

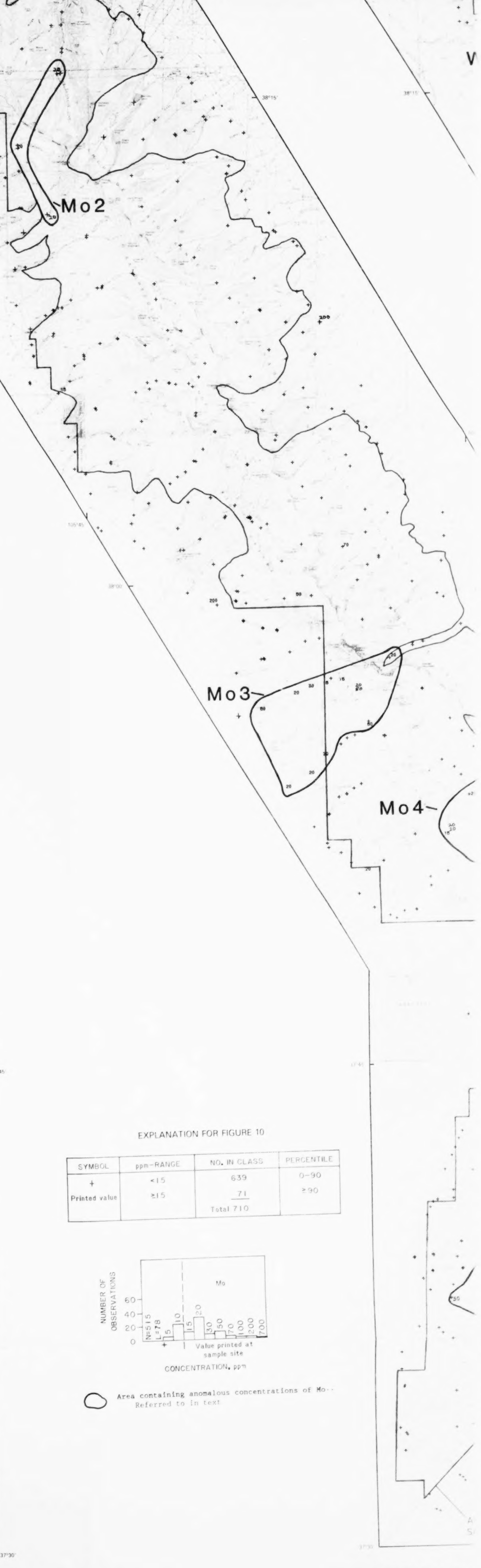
EXPLANATION FOR FIGURE 9

SYMBOL	ppm-RANGE	NO. IN CLASS	PERCENTILE
+	<700	423	0-60
▽	700<1500	126	60-78
▽	1500<5000	75	78-88
⧗	≥5000	86	≥88
		Total 710	

NUMBER OF OBSERVATIONS
180
150
120
90
60
30
0
Ba
L=1
50
70
100
150
200
300
500
700
1000
1500
2000
3000
5000
G=76
+
Value printed at sample site
CONCENTRATION, ppm

Area containing anomalous concentrations of Ba--Referred to in text

FIGURE 9.-Ba IN HEAVY-MINERAL-CONCENTRATE SAMPLES


Mo1
Mo2
Mo3
Mo4

EXPLANATION FOR FIGURE 10

SYMBOL	ppm-RANGE	NO. IN CLASS	PERCENTILE
+	<15	639	0-90
Printed value	≥15	71	≥90
		Total 710	

NUMBER OF OBSERVATIONS
60
40
20
0
Mo
N=515
L=78
5
10
15
20
30
50
70
100
200
700
+
Value printed at sample site
CONCENTRATION, ppm

Area containing anomalous concentrations of Mo--Referred to in text

FIGURE 10.-Mo IN I

SCALE 1:125 000

2 0 2 4 6 8 MILES

2 0 2 4 6 8 KILOMETERS

CONTOUR INTERVAL 80 FEET

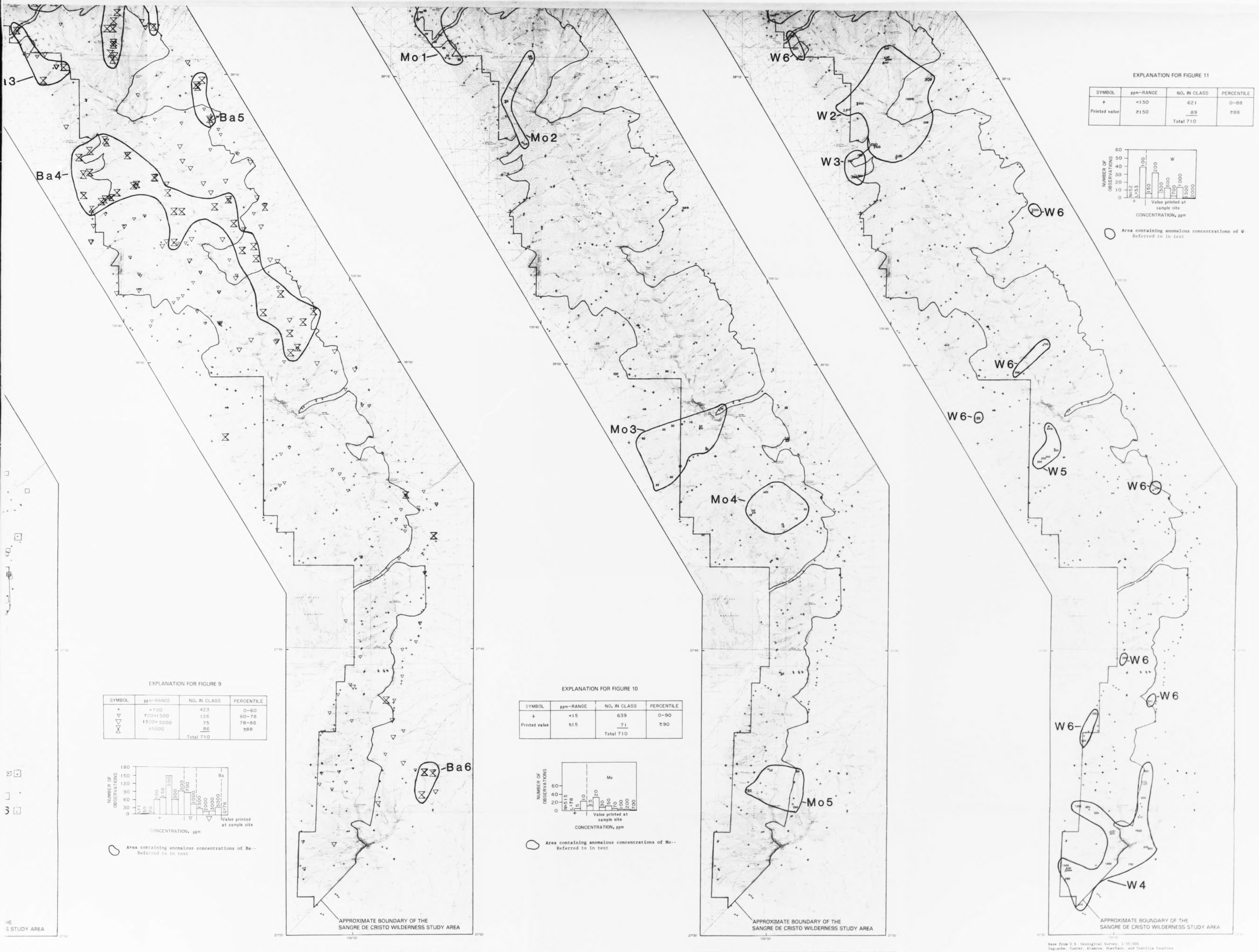
NATIONAL GEODETIC VERTICAL DATUM OF 1929

MAPS SHOWING TRACE-ELEMENT GEOCHEMISTRY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA, SOUTH-CENTRAL COLORADO

By

David R. Zimbelman

1989


a3
Ba4
Ba5
Ba6
HE
S STUDY AREA
Mo1
Mo2
Mo3
Mo4
Mo5
W2
W3
W4
W5
W6
APPROXIMATE BOUNDARY OF THE
SANGRE DE CRISTO WILDERNESS STUDY AREA
37°45'
37°30'
105°30'
38°15'
38°00'
105°45'

TRATE SAMPLES

EXPLANATION FOR FIGURE 9

SYMBOL	ppm–RANGE	NO. IN CLASS	PERCENTILE
+	<700	423	0–60
▽	700<1500	126	60–78
▽	1500<5000	75	78–88
⧗	≥5000	86	≥88
		Total 710	

NUMBER OF OBSERVATIONS
180
150
120
90
60
30
0
L=1
50
70
100
150
200
300
500
700
1000
1500
2000
3000
5000
G=76
Ba
Value printed at sample site
CONCENTRATION, ppm

Area containing anomalous concentrations of Ba--
Referred to in text

FIGURE 9.--Ba IN HEAVY-MINERAL-CONCENTRATE SAMPLES

EXPLANATION FOR FIGURE 10

SYMBOL	ppm–RANGE	NO. IN CLASS	PERCENTILE
+	<15	639	0–90
Printed value	≥15	71	≥90
		Total 710	

NUMBER OF OBSERVATIONS
60
40
20
0
N=515
L=78
5
10
15
20
30
50
70
100
200
700
Mo
Value printed at sample site
CONCENTRATION, ppm

Area containing anomalous concentrations of Mo--
Referred to in text

FIGURE 10.--Mo IN HEAVY-MINERAL-CONCENTRATE SAMPLES

EXPLANATION FOR FIGURE 11

SYMBOL	ppm–RANGE	NO. IN CLASS	PERCENTILE
+	<150	621	0–88
Printed value	≥150	89	≥88
		Total 710	

NUMBER OF OBSERVATIONS
60
50
40
30
20
10
0
N=52
L=53
100
150
200
300
500
700
1000
1500
2000
W
Value printed at sample site
CONCENTRATION, ppm

Area containing anomalous concentrations of W--
Referred to in text

Base from U.S. Geological Survey, 1:50,000
Saguache, Custer, Alamosa, Huerfano, and Costilla Counties

FIGURE 11.--W IN HEAVY-MINERAL-CONCENTRATE SAMPLES

SCALE 1:125 000

2 0 2 4 6 8 MILES

2 0 2 4 6 8 KILOMETERS

CONTOUR INTERVAL 80 FEET

NATIONAL GEODETIC VERTICAL DATUM OF 1929

MAPS SHOWING TRACE-ELEMENT GEOCHEMISTRY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA, SOUTH-CENTRAL COLORADO

By

David R. Zimbelman

1989

Manuscript approved for publication, June 15, 1988

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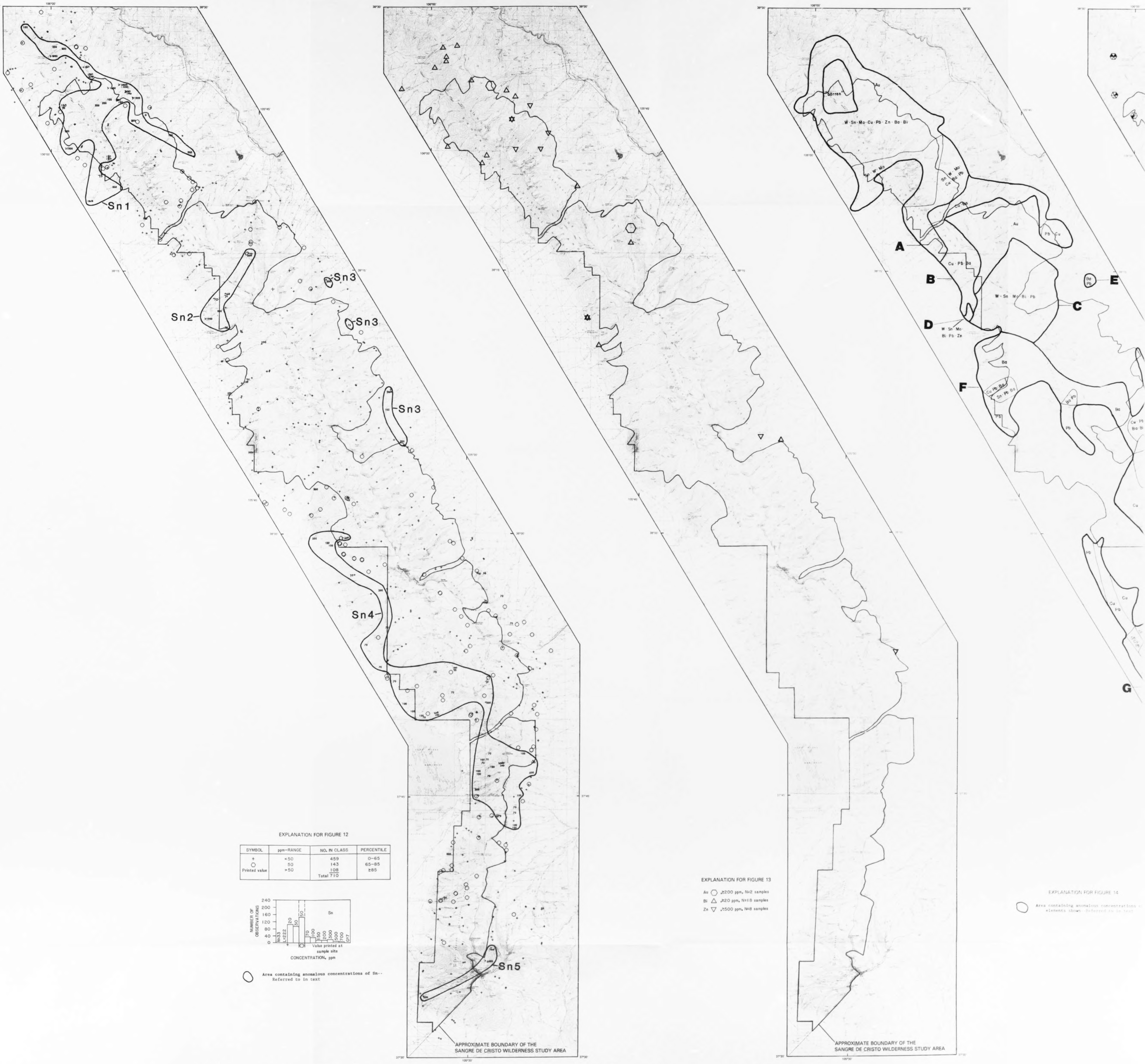
U.S. GEOLOGICAL SURVEY


Sn1
Sn2
Sn3
Sn3
Sn3
Sn4
Sn5
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA
38°30'
106°00'
105°45'
38°15'
105°30'
38°00'
37°45'
37°30'
NUMBER OF OBSERVATIONS
240
200
160
120
80
40
0
N=33
L=222
20
30
50
70
100
150
200
300
500
700
G=7
Sn
Value printed at sample site
CONCENTRATION, ppm

EXPLANATION FOR FIGURE 12

SYMBOL	ppm—RANGE	NO. IN CLASS	PERCENTILE
+	<50	459	0–65
⬡	50	143	65–85
Printed value	>50	108	≥85
		Total 710	

◯ Area containing anomalous concentrations of Sn--
Referred to in text

FIGURE 12.–Sn IN HEAVY-MINERAL-CONCENTRATE SAMPLES

APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA
38°30'
106°00'
105°45'
38°15'
105°30'
38°00'
37°45'
37°30'

EXPLANATION FOR FIGURE 13

Au ⬡ ,≥200 ppm, N=2 samples
Bi △ ,≥20 ppm, N=18 samples
Zn ▽ ,≥500 ppm, N=8 samples

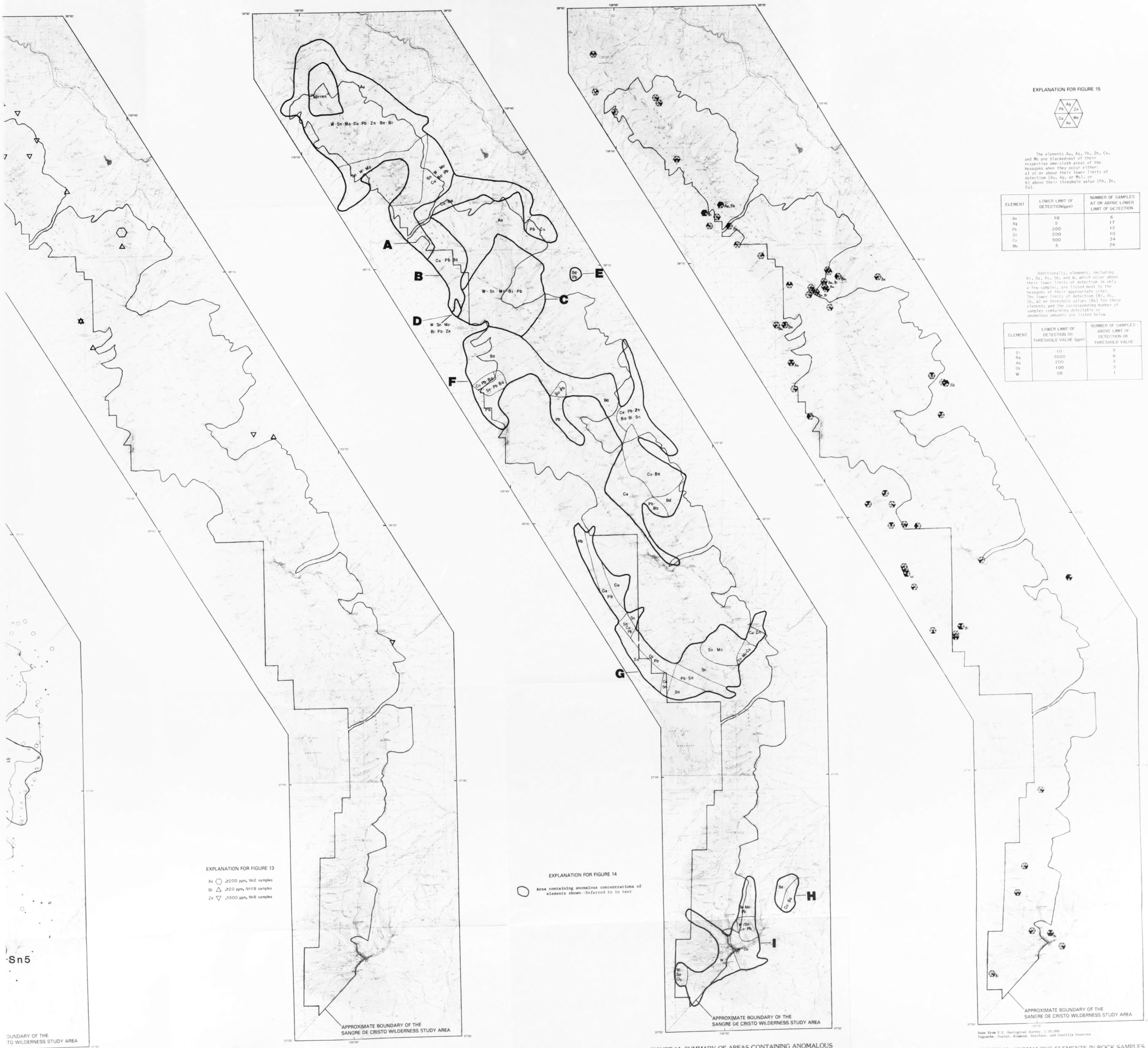
FIGURE 13.–Au, Bi, AND Zn IN HEAVY-MINERAL-CONCENTRATE SAMPLES

A
B
C
D
E
F
G
Au
W·Sn·Mo·Cu·Pb·Zn·Ba·Bi
Sn·W·Mo
Cu·Pb·Ba
W·Sn·Mo·Bi·Pb
W·Sn·Mo
Bi·Pb·Zn
Ba
Pb
Cu
38°30'
106°00'

EXPLANATION FOR FIGURE 14

◯ Area containing anomalous concentrations
elements shown--Referred to in text

SCALE 1:125 000


38°30'
106°00'
105°45'
38°15'
105°30'
38°00'
37°45'
37°30'
A
B
C
D
E
F
G
H
I
Barren
Au
W·Sn·Mo·Cu·Pb·Zn·Ba·Bi
Sn·W·Mo
Sn W Mo Cu Ba Pb
Cu Ba
Au
Pb Cu
Cu·Pb·Ba
W·Sn·Mo·Bi·Pb
Ba Pb
W·Sn·Mo·Bi·Pb·Zn
Ba
Cu·Pb·Ba
Sn·Pb·Ba
Pb
Ba Pb
Pb
Ba
Cu·Pb·Zn Ba·Bi·Sn
Cu·Ba
Cu
Pb Ba
Pb
Cu
Cu Pb
Sn Cu Pb
Sn
Cu
Sn
Sn·Mo
Cu Zn
Sn·Mo·Cu
Pb·Sn
Sn
Ba
Cu Ba
W·Mo Pb
W·Sn Cu·Pb
Cu
W
W·Sn·Cu
As, Sb
Sb
Ba, Bi
Sb
Sn
Bi
As
Sb
Bi
W
Bi
-Sn5
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA

EXPLANATION FOR FIGURE 13

Au ⬡ ,≥200 ppm, N=2 samples
Bi △ ,≥20 ppm, N=18 samples
Zn ▽ ,≥500 ppm, N=8 samples

CONCENTRATE SAMPLES

EXPLANATION FOR FIGURE 14

◯ Area containing anomalous concentrations of elements shown--Referred to in text

FIGURE 14.–SUMMARY OF AREAS CONTAINING ANOMALOUS

MINERAL CONCENTRATE SAMPLES

EXPLANATION FOR FIGURE 15

The elements Au, Ag, Pb, Zn, Cu, and Mo are blacked-out of their respective one-sixth areas of the hexagons when they occur either:
a) at or above their lower limits of detection (Au, Ag, or Mo), or
b) above their threshold value (Pb, Zn, Cu).

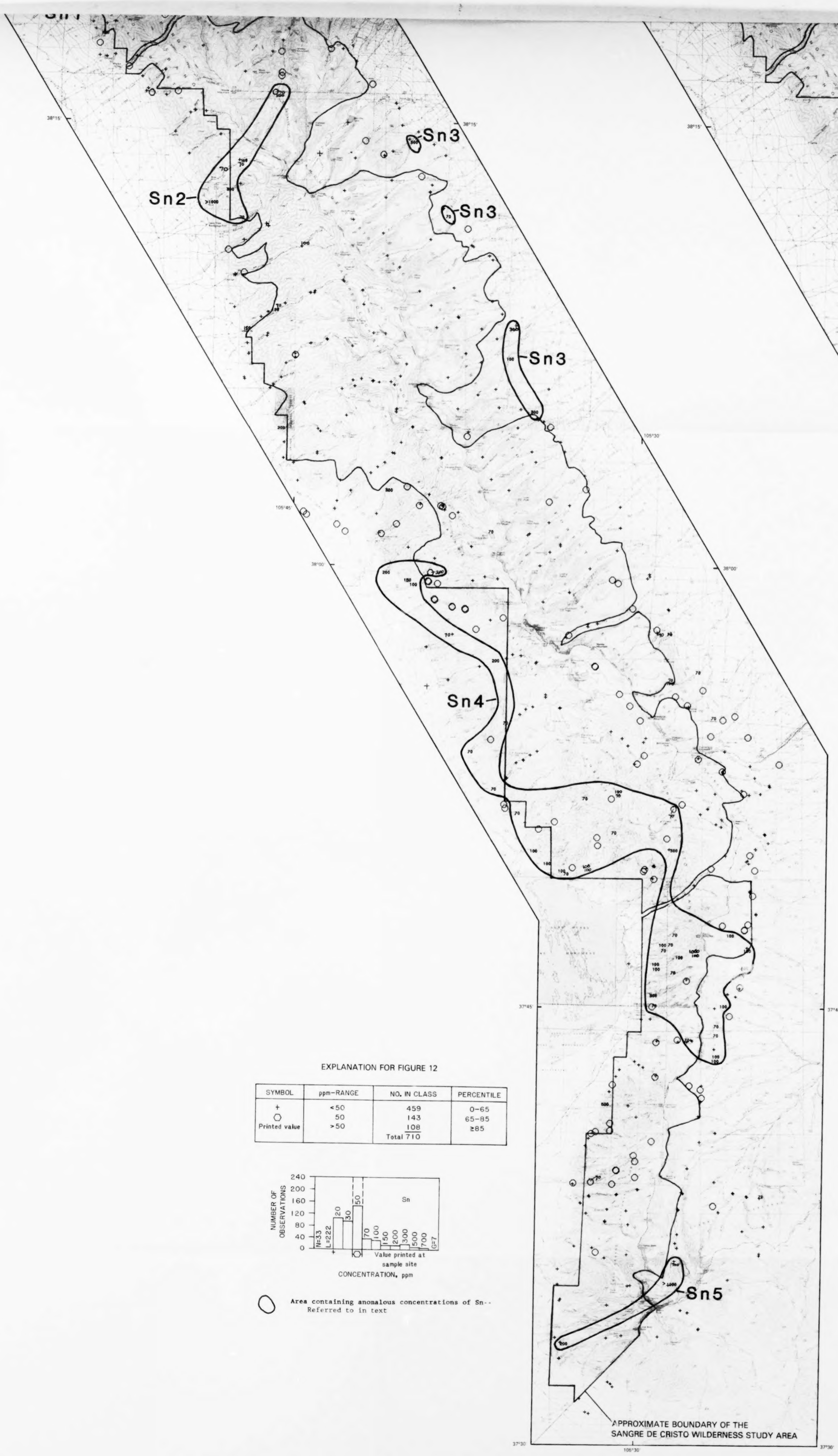
ELEMENT	LOWER LIMIT OF DETECTION(ppm)	NUMBER OF SAMPLES AT OR ABOVE LOWER LIMIT OF DETECTION
Au	10	6
Ag	5	17
Pb	200	12
Zn	200	10
Cu	500	34
Mo	5	26

Additionally, elements, including Bi, Ba, As, Sb, and W, which occur above their lower limits of detection in only a few samples, are listed next to the hexagons at their appropriate sites. The lower limits of detection (Bi, As, Sb, W) or threshold values (Ba) for these elements and the corresponding number of samples containing detectable or anomalous amounts are listed below.

ELEMENT	LOWER LIMIT OF DETECTION OR THRESHOLD VALUE (ppm)	NUMBER OF SAMPLES ABOVE LIMIT OF DETECTION OR THRESHOLD VALUE
Bi	10	9
Ba	3000	8
As	200	3
Sb	100	3
W	50	1

Base from U.S. Geological Survey, 1:50,000
Saguache, Custer, Alamosa, Huerfano, and Costilla Counties

FIGURE 15.–ANOMALOUS ELEMENTS IN ROCK SAMPLES

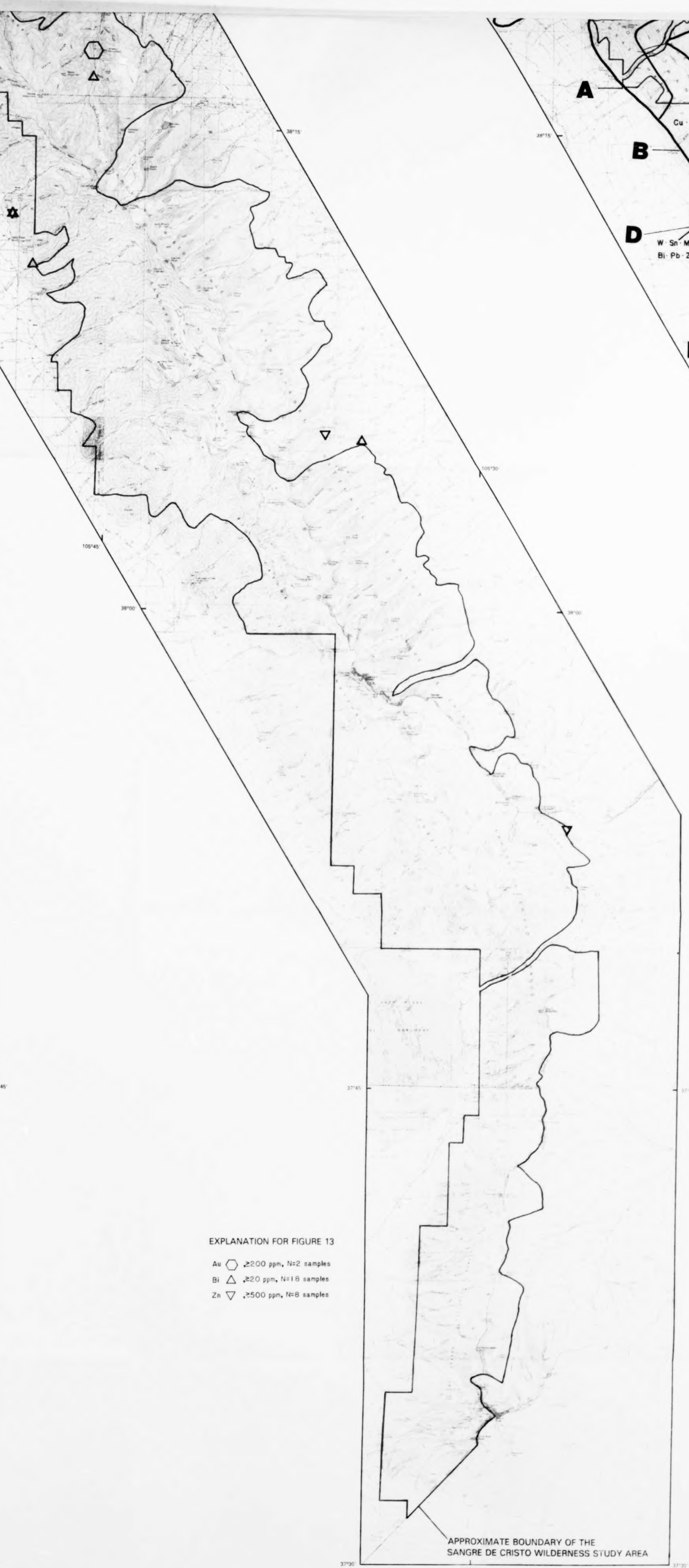

Sn2
Sn3
Sn3
Sn3
Sn4
Sn5
38°15'
105°30'
105°45'
38°00'
37°45'
37°30'
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA
NUMBER OF OBSERVATIONS
Sn
N=33
L=222
Value printed at sample site
CONCENTRATION, ppm

EXPLANATION FOR FIGURE 12

SYMBOL	ppm–RANGE	NO. IN CLASS	PERCENTILE
+	<50	459	0–65
⬡	50	143	65–85
Printed value	>50	108	≥85
		Total 710	

◯ Area containing anomalous concentrations of Sn--
Referred to in text

FIGURE 12.–Sn IN HEAVY-MINERAL-CONCENTRATE SAMPLES


38°15'
105°30'
105°45'
38°00'
37°45'
37°30'
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA

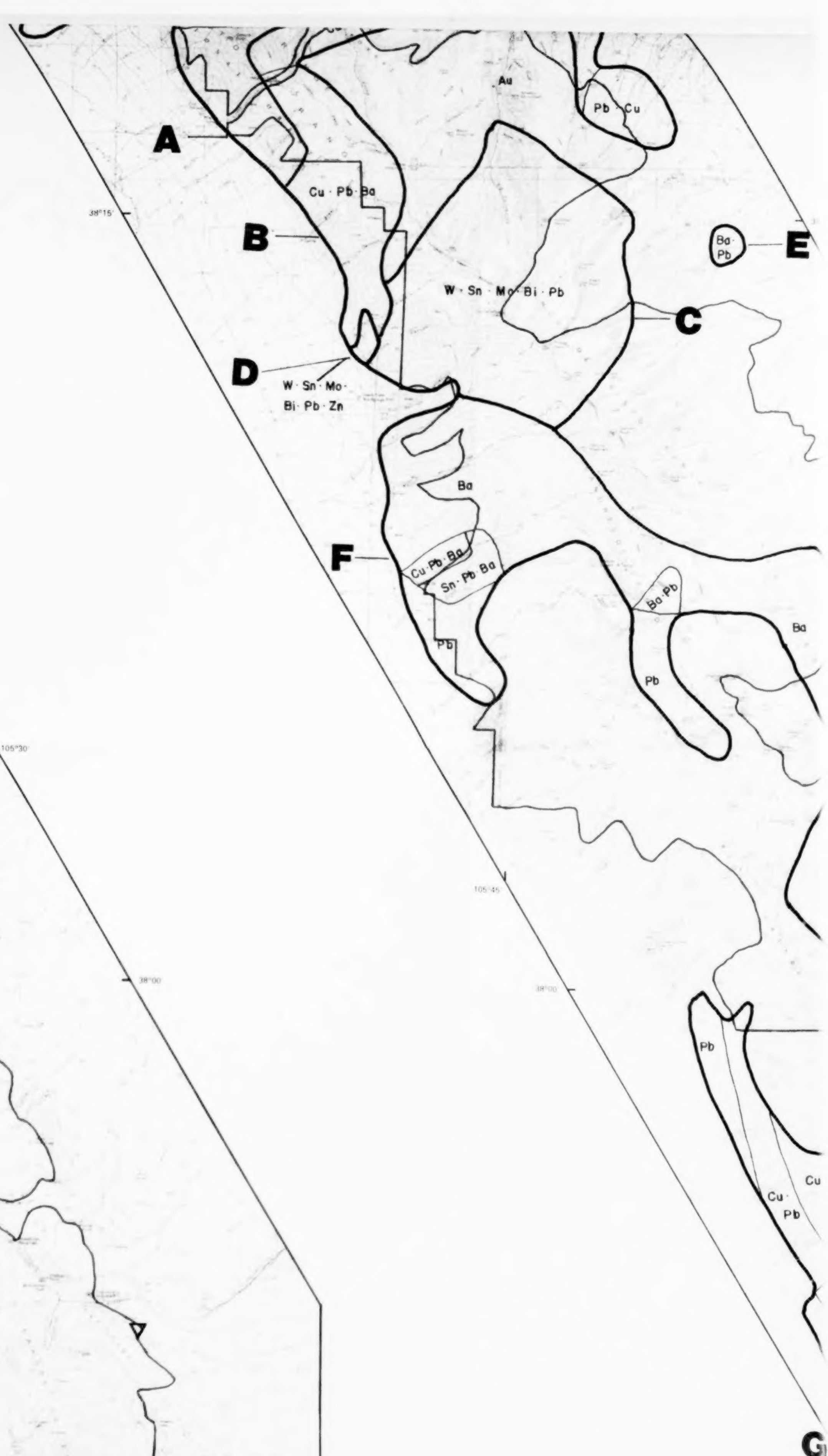
EXPLANATION FOR FIGURE 13

Au ⬡ ,≥200 ppm, N=2 samples
Bi △ ,≥20 ppm, N=18 samples
Zn ▽ ,≥500 ppm, N=8 samples

FIGURE 13.–Au, Bi, AND Zn IN HEAVY-MINERAL-CONCENTRATE SAMPLES

SCALE 1:125 000
2 0 2 4 6 8 MILES
2 0 2 4 6 8 KILOMETERS

CONTOUR INTERVAL 80 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929


A
B
C
D
E
F
G
Au
Pb Cu
Cu Pb Ba
W Sn Mo Bi Pb
W Sn Mo Bi Pb Zn
Ba Pb
Ba
Cu Pb Ba
Sn Pb Ba
Ba Pb
Pb
Pb
Pb
Cu
Pb

EXPLANATION FOR FIGURE 14

◯ Area containing anomalous concentratio
elements shown--Referred to in tex

MAPS SHOWING TRACE-ELEMENT GEOCHEMISTRY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA, SOUTH-CENTRAL COLORADO

By
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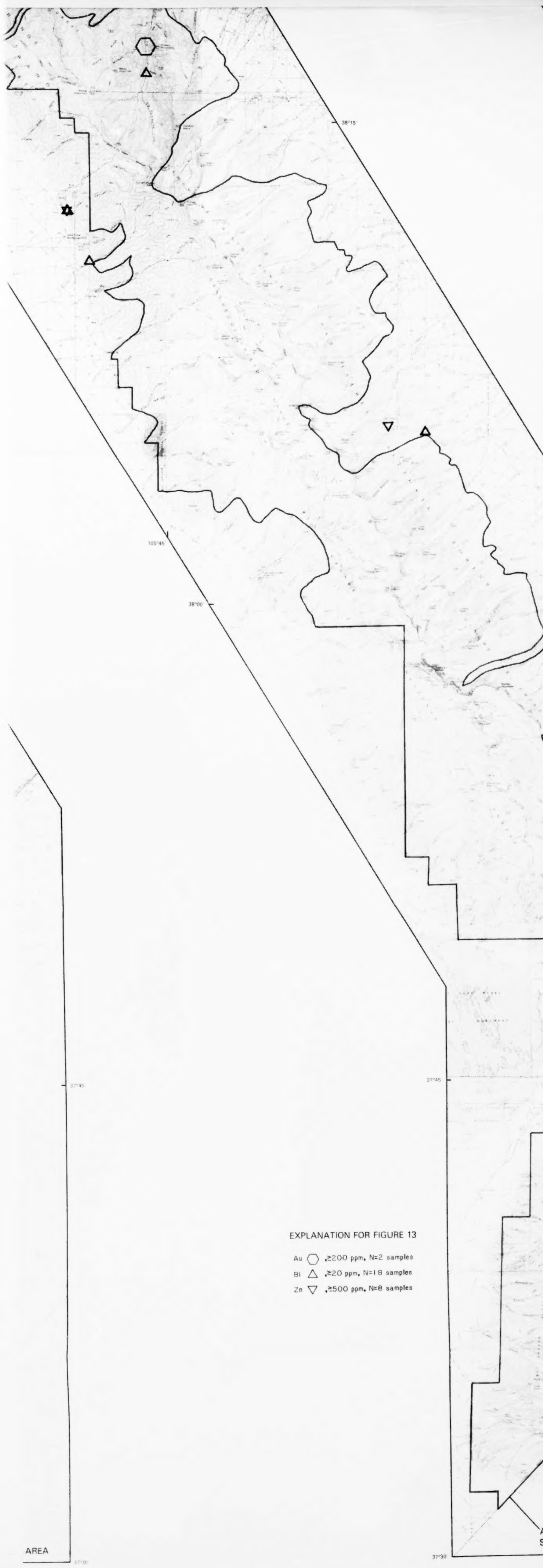
1989

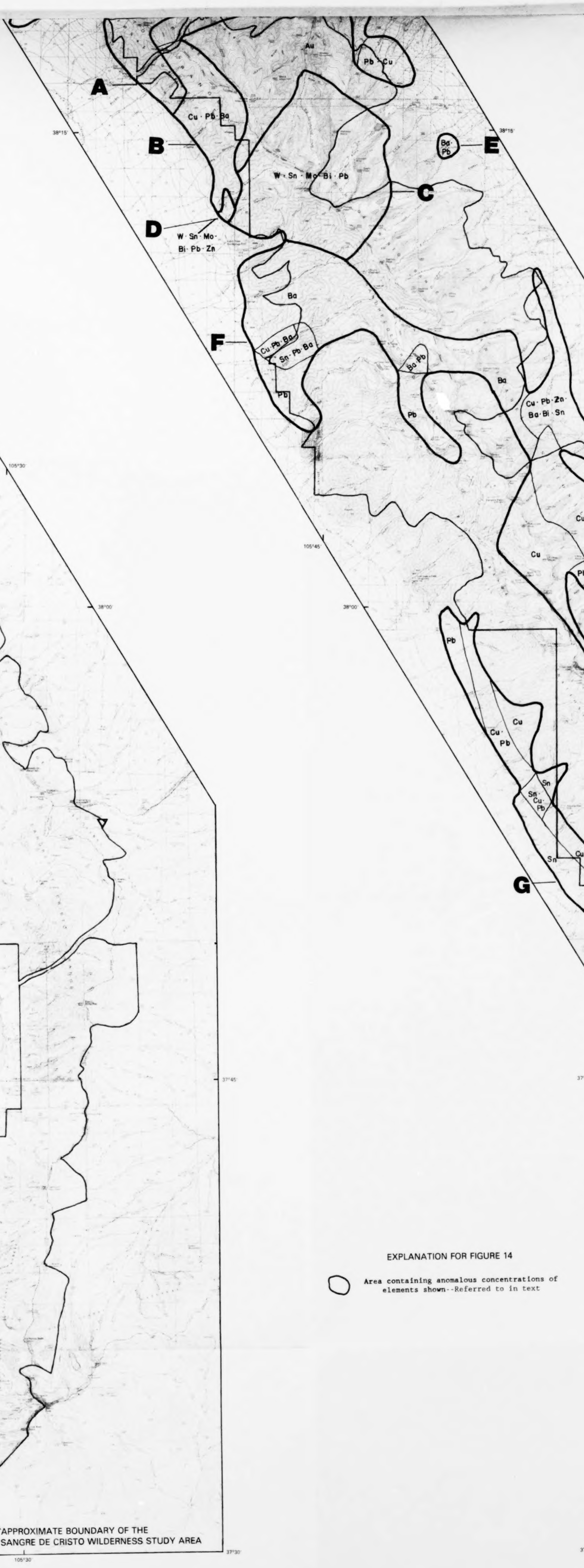

38°15'
105°45'
38°00'
105°30'
37°45'
37°30'
AREA
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA

SAMPLES

EXPLANATION FOR FIGURE 13

Au ⬡ ,≥200 ppm, N=2 samples
Bi △ ,≥20 ppm, N=18 samples
Zn ▽ ,≥500 ppm, N=8 samples

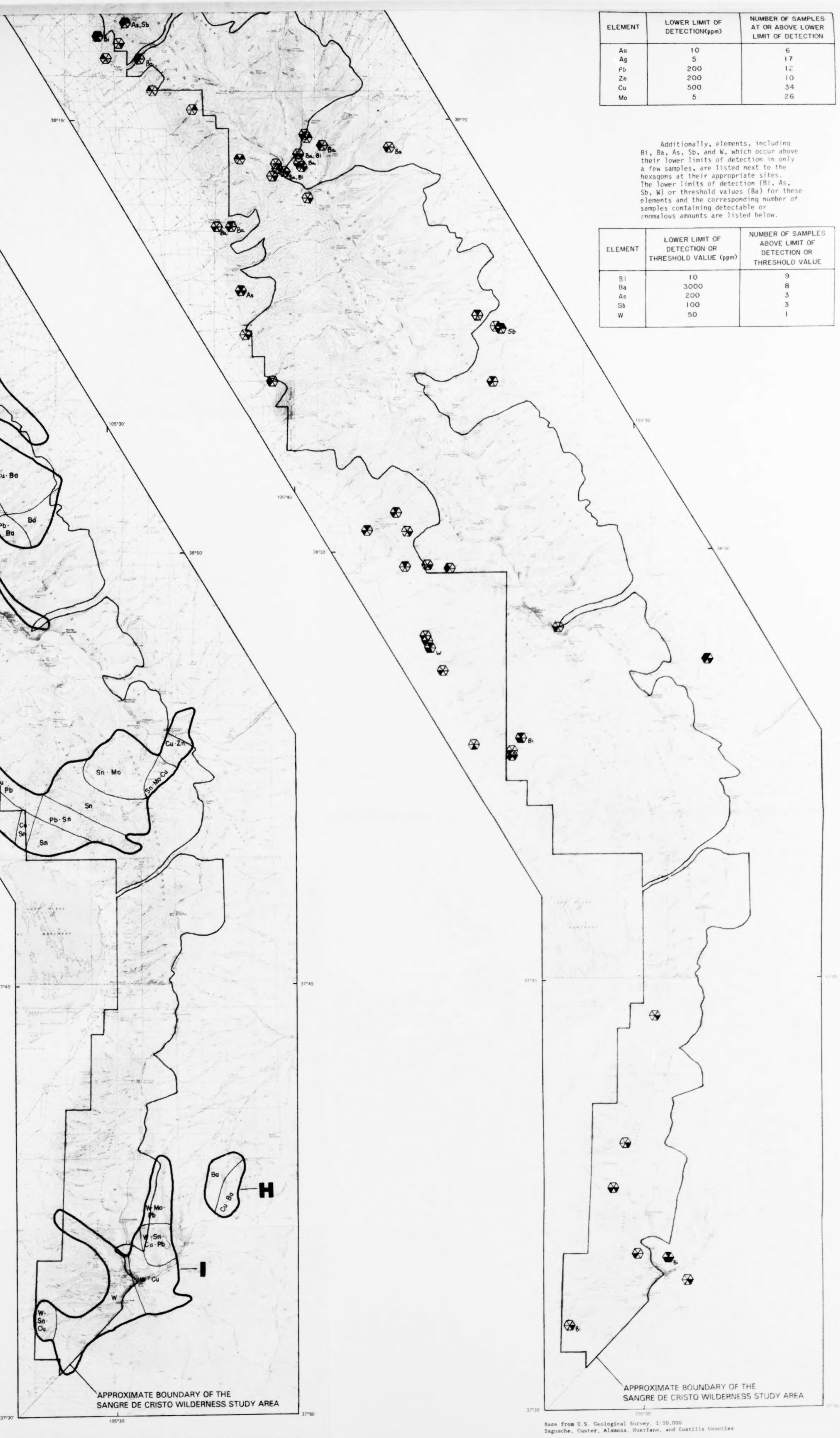
FIGURE 13.–Au, Bi, AND Zn IN HEAVY-MINERAL-CONCENTRATE SAMPLES


A
B
C
D
E
F
G
H
I
Pb · Cu
Cu · Pb · Ba
W · Sn · Mo · Bi · Pb
Ba · Pb
W · Sn · Mo · Bi · Pb · Zn
Ba
Cu · Pb · Ba
Sn · Pb · Ba
Cu · Pb · Zn · Ba · Bi · Sn
Cu · Ba
Pb · Ba
Sn · Mo
Cu · Zn
Pb · Sn
W · Mo · Pb
W · Sn · Cu · Pb
W · Sn · Cu
Cu · Bi
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA
105°30'

EXPLANATION FOR FIGURE 14

Area containing anomalous concentrations of elements shown--Referred to in text

FIGURE 14.–SUMMARY OF AREAS CONTAINING ANOMALOUS ELEMENTS IN HEAVY-MINERAL-CONCENTRATE SAMPLES


As, Sb
Ba
Ba, Bi
Bi
As
Sb
W
Bi
APPROXIMATE BOUNDARY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA
38°15'
105°30'
38°00'
37°45'
37°30'

ELEMENT	LOWER LIMIT OF DETECTION(ppm)	NUMBER OF SAMPLES AT OR ABOVE LOWER LIMIT OF DETECTION
Au	10	6
Ag	5	17
Pb	200	12
Zn	200	10
Cu	500	34
Mo	5	26

Additionally, elements, including Bi, Ba, As, Sb, and W, which occur above their lower limits of detection in only a few samples, are listed next to the hexagons at their appropriate sites. The lower limits of detection (Bi, As, Sb, W) or threshold values (Ba) for these elements and the corresponding number of samples containing detectable or anomalous amounts are listed below.

ELEMENT	LOWER LIMIT OF DETECTION OR THRESHOLD VALUE (ppm)	NUMBER OF SAMPLES ABOVE LIMIT OF DETECTION OR THRESHOLD VALUE
Bi	10	9
Ba	3000	8
As	200	3
Sb	100	3
W	50	1

Base from U.S. Geological Survey, 1:50,000
Saguache, Custer, Alamosa, Huerfano, and Costilla Counties

FIGURE 15.–ANOMALOUS ELEMENTS IN ROCK SAMPLES

SCALE 1:125 000
2 0 2 4 6 8 MILES
2 0 2 4 6 8 KILOMETERS
CONTOUR INTERVAL 80 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

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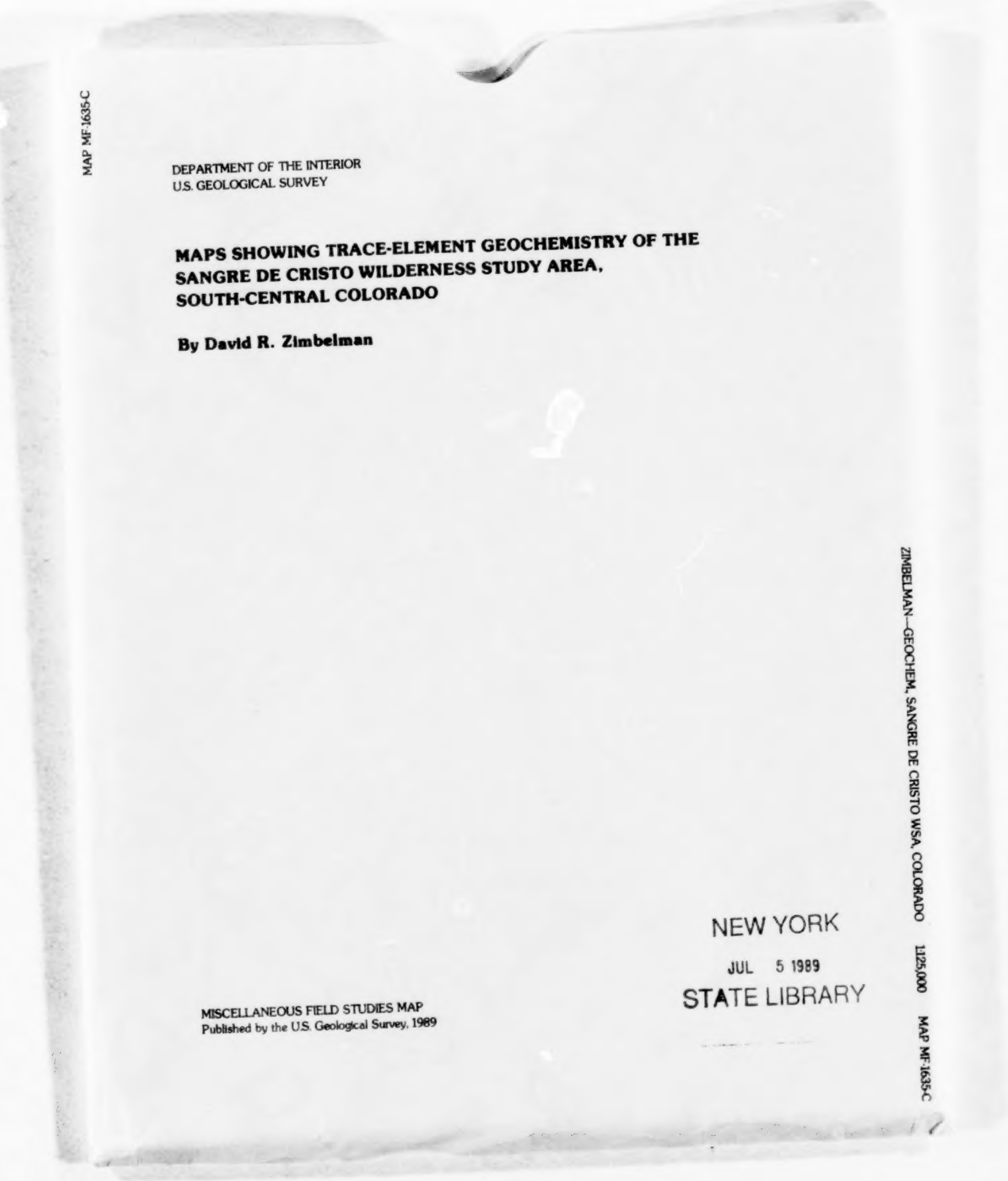

MAP MF-1635-C

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MAPS SHOWING TRACE-ELEMENT GEOCHEMISTRY OF THE SANGRE DE CRISTO WILDERNESS STUDY AREA, SOUTH-CENTRAL COLORADO

By David R. Zimbelman

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MISCELLANEOUS FIELD STUDIES MAP
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ZIMBELMAN—GEOCHEM, SANGRE DE CRISTO WSA, COLORADO 1:125,000 MAP MF-1635-C